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A Study of the Behavior of the
Brittle Lacquer Commercially Known
as Stresscoat When Subjected to
Biaxial Stress of a Known Intensity
and Configuration

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January 16, 1948

Cambridge, Massachusetts
January 16, 1948

Professor J. S. Newell,
Secretary of the Faculty,
Massachusetts Institute of Technology,
Cambridge, Massachusetts .

Dear Sir:

In accordance with the requirements for the Degree of Master of Science in Naval Construction and Engineering, we submit herewith a thesis entitled "A Study of the Behavior of the Brittle Lacquer Commercially Known as Stresscoat When Subjected to Biaxial Stress of Known Intensity and Configuration."

Respectfully,

Respectfully,

Intensity and Configuration."

Stresscoat when subjected to Biaxial stress of known
Behavior of the Brittle Lacquer Commercially known as
we submit herewith a thesis entitled "A Study of the
of Master of Science in Naval Construction and Engineering.
In accordance with the requirements for the Degree

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A STUDY OF THE BEHAVIOR OF THE BRITTLE LACQUER COMMERCIALLY
KNOWN AS STRESSCOAT WHEN SUBJECTED TO BIAXIAL STRESS OF A
KNOWN INTENSITY AND CONFIGURATION

By

Arthur E. Francis
Lieutenant, U.S.Navy
M.E., Stevens Institute
of Technology, 1942

Hubert W. Dannevik
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Submitted in partial fulfillment of the
requirements for the degree of
MASTER OF SCIENCE IN NAVAL CONSTRUCTION AND ENGINEERING
at the
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

1948

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 KNOWN AS STRENGTH WHEN SUBJECTED TO A
 KNOWN INTENSITY AND DURATION

BY

Thesis

F7

Hubert W. Dammann
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The authors wish to express their appreciation and indebtedness to the following persons:

To Professor William M. Murray for the suggestion of the specific problem and for guidance during the investigation.

To Mr. V. L. Walsh for instruction in Stresscoat and strain gauge technique and for practical assistance rendered during the investigation.

To Mr. C. E. Lutts and Mr. M. Graham of the Materials Testing Laboratory, Boston Naval Shipyard for the original suggestion of the field of this investigation and for aid in securing the manufacture of the apparatus.

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TABLE OF SYMBOLS

- e_a - Average axial strain in specimen obtained from strain gauges, micro inches/inch.
- e_c - Average circumferential strain in specimen obtained from strain gauges, micro inches/inch.
- e_{max} - Average maximum strain in the specimen obtained from strain gauges, micro inches/inches.
- e_{min} - Average minimum strain in the specimen obtained from strain gauges, micro inches/inch.
- e - Lateral strain in the calibration bar. - vE - micro inches/inch.
- E_a - Average axial strain in specimen obtained from strain gauges and corrected for lateral sensitivity, micro inches/inch.
- E_c - Average circumferential strain in specimen obtained from strain gauges and corrected for lateral sensitivity, micro inches/inch.
- E_{max} - Average maximum strain in specimen corrected for lateral sensitivity, micro inches/inch.
- E_{min} - Average minimum strain in specimen corrected for lateral sensitivity, micro inches/inch.
- E - Average longitudinal strain determined from several calibration bars, micro inches/inch.
- E_m - Young's Modulus.
- t - Time of loading specimen, seconds.
- T_d - Temperature of coating surface during test, deg. F.
- $S\#$ - Number of particular grade of Stresscoat used.
- D - Deviation or $E - E_{max}$, micro inches/inch.
- $\%D$ - Percent deviation or $(100) (E - E_{max}) / (E_{max})$, %.
- $\%D_s$ - Percent stress deviation, $(S_{bar} - S_{max}) (100) / S_{max}$.

TABLE OF SYMBOLS

| | |
|------------------|--|
| ϵ_a | - Average axial strain in specimen obtained from strain gauges, micro inches/inch. |
| ϵ_c | - Average circumferential strain in specimen obtained from strain gauges, micro inches/inch. |
| ϵ_{max} | - Average maximum strain in the specimen obtained from strain gauges, micro inches/inch. |
| ϵ_{min} | - Average minimum strain in the specimen obtained from strain gauges, micro inches/inch. |
| ϵ | - Lateral strain in the calibration bar. - $\nu \epsilon$ - micro inches/inch. |
| ϵ_a | - Average axial strain in specimen obtained from strain gauges and corrected for lateral sensitivity, micro inches/inch. |
| ϵ_c | - Average circumferential strain in specimen obtained from strain gauges and corrected for lateral sensitivity, micro inches/inch. |
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| ϵ | - Average longitudinal strain determined from several calibration bars, micro inches/inch. |
| E_m | - Young's Modulus. |
| t | - Time of loading specimen, seconds. |
| T_b | - Temperature of coating surface during test, deg. F. |
| $\Delta\epsilon$ | - Number of carticular grade of stresscoat used. |
| σ | - Deviation or $\epsilon - \epsilon_{max}$, micro inches/inch. |
| $\% \epsilon$ | - Percent deviation or $(100) (\epsilon - \epsilon_{max}) / \epsilon_{max}$, %. |
| $\% \sigma$ | - Percent stress deviation, $(100) (\sigma) / \epsilon_{max}$. |

TABLE OF SYMBOLS

- S_{max} - Maximum stress in the specimen, psi.
- S_{min} - Minimum stress in the specimen, psi.
- S_{bar} - Stress indicated by calibration bar, psi.
- v - Poisson's ratio.
- v_o - Poisson's ratio of steel on which strain gauges were calibrated, .285.
- k - A constant with value of .021 for type A-3 strain gauges.

TABLE OF SYMBOLS

| | | |
|----------------|---|--|
| σ_{max} | - | Maximum stress in the specimen, psi. |
| σ_{min} | - | Minimum stress in the specimen, psi. |
| σ_{par} | - | Stress indicated by calibration bar, psi. |
| ν | - | Poisson's ratio. |
| ν_o | - | Poisson's ratio of steel on which strain gauges were calibrated, .282. |
| K | - | A constant with value of .021 for type A-2 strain gauges. |

SUMMARY

Results

It was found that more strain was required to produce a crack pattern under tensile load than was indicated by the calibration bar. The opposite effect was observed when the specimen was subjected to internal pressure. The presence of crazing decreased the sensitivity of Stresscoat. The presence of a strain crack pattern in one direction has a yet unexplained effect on the sensitivity of Stresscoat to failure in a perpendicular direction.

Object

The purpose of this investigation was to expand the limited knowledge of the behavior of Stresscoat when subjected to a biaxial stress condition different from that stress condition existing in the calibration bar and to correlate the information obtained in such a manner that more precise quantitative determinations are possible. For the benefit of future experimenters in this field an attempt was made to analyze any peculiarities in the behavior of the Stresscoat which were observed.

Procedure

The actual strain on the surface of a hollow cylindrical test specimen was determined with strain gauges when the surface of the vessel was subjected to different combinations of two-dimensional strain. These combinations of strain were produced by applying axial loading and internal pressure to the specimen. The strains causing a crack

Results

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Procedure

The actual strain on the surface of a hollow cylindrical cal test specimen was determined with strain gauges when the surface of the vessel was subjected to internal pressure. A combination of two-dimensional strain gauges was used to determine strain were produced by internal pressure. The internal pressure was applied to the specimen to be examined. The strain gauges were attached to the specimen.

SUMMARY

pattern in the Stresscoat applied to the test specimen in the vicinity of the strain gauges were compared with the strains indicated by the calibration bars.

Conclusion

The deviation between actual strain and the strain indicated by the Stresscoat may vary from zero to thirty percent depending upon the ratio of minimum strain to the maximum strain in the specimen. When strain, indicated by Stresscoat, is used to calculate stress the deviation between actual stress and calculated stress is reduced to a maximum value of approximately fifteen percent.

Recommendations

Further investigation of the behavior of Stresscoat should be conducted under controlled atmospheric conditions. Apparatus should be designed by which axial load and internal pressure may be applied uniformly and simultaneously to the specimen, to facilitate handling the creep characteristic of Stresscoat at all values of S_{min}/S_{max} . Evaluation of Poisson's ratio and the modulus of elasticity of Stresscoat, combined with the values of strain for various values of S_{min}/S_{max} would allow the determination of the theory of failure of Stresscoat.

SUMMARY

pattern in the stresscoat applied to the test specimen in the vicinity of the strain gauges were compared with the strains indicated by the calibration bars.

Conclusion

The deviation between actual strain and the strain indicated by the stresscoat may vary from zero to thirty percent depending upon the ratio of minimum strain to the maximum strain in the specimen. When strain, indicated by stresscoat, is used to calculate stress the deviation between actual stress and calculated stress is reduced to a maximum value of approximately fifteen percent.

Recommendations

Further investigation of the behavior of stresscoat should be conducted under controlled atmospheric conditions. Apparatus should be designed by which axial load and internal pressure may be applied uniformly and simultaneously to the specimen, to facilitate handling the cross characteristics of stresscoat at all values of $\epsilon_{min}/\epsilon_{max}$. Investigation of Poisson's ratio and the modulus of elasticity of stresscoat, combined with the values of strain for which values of $\epsilon_{min}/\epsilon_{max}$ would allow the determination of the level of strains of stresscoat.

INTRODUCTION

Stresscoat is the latest widely known development in the field of brittle coatings used for stress-strain analysis of the component parts of structures. When a base material is subjected to a progressively increasing stress, the distortion in the base material will eventually cause any brittle coating adhering to its surface to fail by cracking. In most coats these cracks occur in a direction perpendicular to the direction of the principal stress. If the base material is subjected to such large stresses that its yield point is exceeded and very large amounts of distortion occur, the brittle coating will flake or spawl off. One of the early observed instances of this phenomenon was the cracking or flaking off of mill scale on structural members under load. The places in the structure where this breakdown of scale first occurred were points of weakness or stress concentration. Early investigators also noticed that the presence of a coat of white-wash on structural members increased the ease with which a failure in the mill scale could be observed. Cracking and spawling of bitumastic enamel used on shipboard was another early example of this phenomenon. Attempts to utilize these observations for quantitative measurements were unsuccessful.

The search for a brittle coating which would be capable of dependable quantitative, as well as qualitative, interpretation continued in the United States and other countries (principally Great Britain and Germany). Many substances

Stressing is the latest widely known development in the field of brittle coatings used for stress-strain analysis of the component parts of structures. When a base material is subjected to a progressively increasing stress, the distortion in the base material will eventually cause any brittle coating adhering to its surface to fail by cracking. In most cases these cracks occur in a direction perpendicular to the direction of the principal stress. If the base material is subjected to such large stresses that its yield point is exceeded and very large amounts of distortion occur, the brittle coating will flake or spall off. One of the early observed instances of this phenomenon was the cracking or flaking off of mill scale on structural members under load. The places in the structures where this breakdown of scale first occurred were points of weakness or stress concentration. Early investigators also noticed that the presence of a coat of white-wash on structural members increased the ease with which a failure in the mill scale could be observed. Cracking and spalling of discolored steel used on shipboard was another early example of this phenomenon. Attempts to utilize these coatings for quantitative measurements were unsuccess-ful. The search for a brittle coating which could be used for accurate quantitative, as well as qualitative, information was continued in the United States and other countries (principally Great Britain and Germany). Early investigators

such as sugar, sulphur, plaster of Paris, and various resins were tried. The late Professor A. V. DeForest of Massachusetts Institute of Technology did considerable preliminary work which contributed to the final development of the present day Stresscoat. He tried various methods of coating application as well as types of material for the coating itself. The methods of application investigated were:

- a. Covering the surface with powdered material which was subsequently heated until it melted to form a continuous coat.
- b. Brushing, dipping, or spraying the molten coating on the base material.
- c. Brushing, dipping, or spraying the coating, dissolved in a solvent which evaporates as the coating assumes its brittle condition.

Mr. Greer Ellis (8) in 1937 determined the composition of a brittle lacquer having those characteristics which made it ideal for qualitative and quantitative strain indicating. The desirable characteristics are:

- a. Ability to fail by cracking due to strains within the elastic range of most engineering materials.
- b. Crack sensitivity fairly independent of coat thickness.
- c. Ability to dry to brittleness, within a reasonable length of time and at normal temperatures.
- d. Appearance of cracks should be easily discernible.

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- d. Proper alloy (?) in 1937 determined the composition of a brittle lacquer having those characteristics which made it ideal for qualitative and quantitative strain indication. The desirable properties are:
 - a. Ability to melt by heating to a strain within the elastic limit of most structural materials.
 - b. Coats relatively fairly independent of coat thickness.
 - c. Ability to be brittle, yet in a plastic state at room and at high temperatures.
 - d. Resistance of strain recovery after heating.

This brittle lacquer is currently known, commercially, as Stresscoat. It is manufactured and distributed by the Magnaflux Corporation. It is excellent for qualitative experimentation and the manufacturer claims that quantitative results obtained from tests conducted under controlled loading and atmospheric conditions are accurate within about 10%.

A calibration bar is employed to interpret the results obtained when using Stresscoat. The bar is secured at one end only in a jig so that it approximates a cantilever beam. The specimen under investigation and the calibration bar are sprayed and dried under identical conditions. After drying, the specimen is stressed and the free end of the calibration bar is depressed a known amount in the jig. This produces a known stress and strain in the bar varying from zero at the free end to a maximum value at the fixed end. Cracks appear in the Stresscoat over that portion of the bar in which the strain exceeds the value which will cause failure in the particular coating involved. Current practice is to assume that the strain under the last crack toward the free end of the bar is the same strain which exists under the first crack to appear in the Stresscoat on the specimen. The validity of this assumption is open to question because the calibration bar is subjected to uniaxial stress with a constant ratio between the principal strains produced; while a material under investigation may be subjected to any of an unlimited number of biaxial stress conditions, each causing a particular combination of two or three dimensional strains.

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Only a limited amount of work investigating the behavior of Stresscoat under biaxial stress has been done and very little has been published. Eric Olsen (11) in 1941 investigated the accuracy of quantitative Stresscoat determinations when the specimen was subjected to a two-dimensional strain condition different from that existing in the calibration bar for a few specific two-dimensional strain conditions. It is the aim of this report to further develop the investigation in this field by conducting enough consecutive tests in each of a few particular conditions of two-dimensional strain so that some knowledge of the magnitude of the deviation between the calibration bar indicated strain and the actual strain in the specimen may be learned.

During the course of the experiments various peculiarities of the general behavior of Stresscoat were observed. Although this information was secondary to the original purpose of the investigation it has been recorded and discussed because it was felt that it may be of value to those who will continue with further work in this field.

Only a limited amount of work investigating the behavior of stressors under physical stress has been done and very little has been published. This paper (11) in 1941 investigated the accuracy of quantitative stressors determined when the animal was subjected to a two-dimensional strain condition different from that existing in the calibration bar for a few specific two-dimensional strain conditions. It is the aim of this report to further develop the investigation in this field by conducting enough comparative tests in each of a few particular conditions of two-dimensional strain so that some knowledge of the magnitude of the deviation between the calibration bar indicated strain and the actual strain in the specimen may be learned. During the course of the experiments various peculiarities of the general behavior of stressors were observed. Although this information was secondary to the main purpose of the investigation it has been reported and discussed because it was felt that it may be of value to those who will continue with further work in this field.

PROCEDURE

The first step in the investigation was to select a test specimen in which at least two different conditions of biaxial stress could be set up. The specimen used was a thin walled tube of low carbon steel which was made into a pressure vessel by welding forged plugs into each end. The outboard ends of these plugs were machined to fit a self centering attachment on the tensile testing machine used. The end plugs were drilled and tapped to receive high pressure copper tube and fittings for applying the internal pressure to the test specimen. Four SR-4 electric strain gauges were affixed at equal intervals around the outside of the tube far enough from the ends to eliminate end effects. Two of these strain gauges were circumferential and two were axial. The gauges in the same direction were placed on opposite sides of the specimen. The dimensions and composition of the specimen were chosen to give strains applicable to Stresscoat investigation, within the elastic limits of the material and the capacity of the loading devices.

The second step was the mastery of Stresscoat and strain gauge technique. About six weeks were consumed before it was felt that enough proficiency had been gained in applying Stresscoat, controlling conditions during the drying and testing, and observing the first cracks to produce reliable data. During the early part of this educational period, an attempt was made to learn by experience, but the

PROCEDURE

The first step in the investigation was to select a test specimen in which at least two different conditions of biaxial stress could be set up. The specimen used was a thin walled tube of low carbon steel which was made into a pressure vessel by welding formed disks into each end. The outboard ends of these disks were machined to fit a self centering attachment on the tensile testing machine used. The end disks were drilled and tapped to receive high pressure copper tube and fittings for applying the internal pressure to the test specimen. Four SR-4 electric strain gauges were affixed at equal intervals around the outside of the tube far enough from the ends to eliminate end effects. Two of these strain gauges were circumferential and two were axial. The gauges in the same direction were placed on opposite sides of the specimen. The dimensions and composition of the specimen were chosen to give strains applicable to stress-strain investigation, within the elastic limits of the material and the capacity of the loading device.

The second area was the mastery of stress-strain and strain rate technique. About six weeks were consumed before it was felt that enough proficiency had been gained in stress-strain technique, controlling conditions during the drying and testing, and observing the first signs of plastic deformation. During the early part of this educational period, an attempt was made to learn by experience, but the

detailed instructions published by the manufacturer (16) were carefully studied prior to taking the data incorporated in this report. Such a course was considered to be most conducive to observing as many of the characteristics of Stresscoat as possible. The Stresscoat was applied in a special spray booth in the basement of the Institute and the drying took place in the DeForest Memorial Stress Laboratory. The pressure runs were also made in the Stress Laboratory, but the tensile runs were made in the Material Testing Laboratory of the Institute.

Anticipation of atmospheric conditions, which would exist twelve to twenty-four hours after the application of the coat, was required in choosing the proper grade of lacquer. The grade chosen should fail at a practical value of strain, but should not be so sensitive as to craze during the drying period. The choice was made with the aid of a chart provided by the manufacturer. Difficulty was encountered in obtaining sufficient sensitivity for the tensile runs without the occurrence of crazing due to the large and rapid fluctuation of the temperature in the Institute during the night. This problem was defeated by covering the specimen and calibration bars with a large cardboard enclosure during the drying period. A lighted electric bulb inside this enclosure served to keep the coatings at a sufficiently high temperature to prevent crazing. Several times it was necessary to artificially cool the coatings in order to obtain cracking at a practical value of strain. The specimen

[illegible]

and the calibration bars were maintained at the same constant temperature during each test.

Although an attempt was made to load the specimen in as short a time as possible, the time of loading varied from thirty seconds to three minutes. The creep of the coating during a finite loading time was an additional important variable. As the time of loading increases the sensitivity of the coat decreases. If the time of loading is long enough, formation of the crack pattern may never occur. This creep phenomenon must be considered if the correct interpretation of the test results is to be obtained. This is accomplished either by loading the calibration bars gradually in the same period of time as the specimen was loaded or by loading the calibration bars in one second and then applying a creep correction factor. This correction is made by utilizing the creep correction charts furnished by the manufacturer. Six calibration bars were used for each run and three were loaded in each of the ways described above.

The pressure runs were made with the specimen freely supported by the ends in a wooden cradle. The hydraulic pump, used to supply the water pressure internally to the specimen, was of the jack type. It was equipped with a pressure gauge which allowed a rough estimate of the internal pressure, and also permitted us to control the rate of load application. The tensile or axial loading runs were made by pulling the specimen in a conventional tensile

and the calibration bars were maintained at the same constant temperature during each test.

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testing machine. The pressure gauge and the beam balance readings were not essential to the data as the strain gauges provided the actual strains on the surface of the specimen. It was necessary to correct for lateral sensitivity of the SR-4 strain gauges.

A total of twenty-seven runs were made on the test specimen, but the data of runs seventeen through twenty-seven was considered to be that which represented the best technique, and consequently only these eleven runs were used.

It was considered of interest to investigate the effect of the presence of severe crazing on the behavior of the Stresscoat. An experiment was attempted using six calibration bars, three of which were artificially crazed by exposure to a low temperature for a short period of time, while the other three were maintained with a clear coat. The bending test was applied to these bars after all six of them had returned to the same temperature and had remained at that temperature for about one-half of an hour. Time loading of these bars was used because the progress of the cracks could be followed on the crazed bars with more ease and accuracy than would be the case if a one second load were applied.

After each tensile crack pattern had been formed on the specimen, and an interval of time exceeding twice the time during which the load was applied and held had elapsed, the specimen was subjected to a pressure run. The results

testing machine. The pressure gauge and the beam distance readings were not essential to the data as the strain gauges provided the actual strains on the surface of the specimen. It was necessary to correct for lateral sensitivity of the SR-4 strain gauges.

A total of twenty-seven runs were made on the test specimen, but the data of runs seventeen through twenty-seven was considered to be that which represented the best technique, and consequently only these eleven runs were used.

It was considered of interest to investigate the effect of the presence of severe strain on the behavior of the specimen. An experiment was attempted using the self-heating bars, three of which were artificially strained by exposure to a low temperature for a short period of time, while the other three were maintained with a slight load. The results were well applied to these runs and all of the data was retained for the same temperature and rate of strain. The temperature for about 1000 psi was maintained at 1000 psi. The loading of these bars was used because the process of the cracks could be related to the stress and strain rate and accuracy was only to the same if the same load were applied.

After the strain bars had been tested on the specimen, and an interval of time expended, the time during which the test was applied was noted and the specimen was subjected to a stress of 1000 psi.

of these runs indicated the desirability of further investigation of the nature of cracking of Stresscoat in a direction perpendicular to cracks already produced on the specimen by a previous test. Therefore, a fifteen inch square of celluloid one-eighth of an inch thick was coated with Stresscoat. After drying, this flat plate was secured by one edge in a cantilever fashion and the opposite edge was depressed a certain distance in a given length of time. After allowing time for the creep recovery of the Stresscoat, the plate was turned ninety degrees and the identical experiment was repeated. The nature of the total crack pattern was then observed.

An investigation of the conformance of the calibration bar to beam theory and Poisson's ratio effect was made by checking the lateral strain at various points along the bar with SR-4 strain gauges.

The strain gauge readings and axial load or internal pressure at the appearance of the first crack in the coating on the specimen were recorded. The strain corresponding to the last crack on the calibration bars was taken as the calibrating strain. A flash light focused perpendicular to the anticipated direction of the cracks was a necessary aid in catching the first crack. The actual strains were compared with those indicated by the calibration bar. The deviations of the calibration bar strain from actual strain for the pressure and tensile runs were compared. For the tests involving the calibration bars alone the results occurring

of these runs indicated the desirability of further investigation of the nature of cracking of stresscoat in a direction perpendicular to cracks already produced on the specimen by a previous test. Therefore, a fifteen inch square of cold-rolled one-eighth of an inch thick was coated with stresscoat. After drying, this flat plate was secured by one edge in a cantilever fashion and the opposite edge was depressed a certain distance in a given length of time. After allowing time for the creep recovery of the stresscoat, the plate was turned ninety degrees and the identical experiment was repeated. The nature of the total crack pattern was then observed.

An investigation of the compliance of the calibration bar to beam theory and Poisson's ratio effect was made by checking the lateral strain at various points along the bar with 25-4 strain gauges.

The strain gauge positions and axial load or internal pressure at the appearance of the first crack in the coating on the specimen were recorded. The strain corresponding to the first crack on the calibration bars was taken as the calibration strain. A thin light focused perpendicular to the anticipated direction of the cracks was a necessary aid in obtaining the first crack. The actual strains were compared with those indicated by the calibration bars. The deviations of the calibration bar strain from actual strain for the pressure and tensile runs were compared. For the test involving the calibration bars along the results, occurring

under different types of treatment were compared. All comparisons were straight forward and involved no complicated computations.

For a detailed description of the equipment used see Appendix A.

under different types of treatment were compared. All com-
parisons were straight forward and involved no complicated
calculations.

For a detailed description of the experiment used see

Appendix A.

RESULTS

Table I

Internal Pressure Applied to Cylindrical Specimen

| Run No. | E_a | E_c | $\frac{E_{min}}{E_{max}}$ | E | D | %D | t | T_d | #stress-coat |
|----------------|-------|-------|---------------------------|-----|-----|------|-----|-------|--------------|
| 17 | 206 | 835 | .247 | 900 | 65 | 78 | 225 | 66.0 | 1204 |
| 18 | 197 | 780 | .252 | 953 | 173 | 22.2 | 120 | 70.5 | 1204 |
| 19 | 130 | 443 | .293 | 490 | 47 | 10.6 | 40 | 73.5 | 1206 |
| 20 | 203 | 830 | .245 | 852 | 22 | 2.7 | 50 | 71.5 | 1205 |
| 21 | 200 | 894 | .224 | 984 | 90 | 10.1 | 60 | 71.0 | 1205 |
| Average value: | | | .252 | | | 10.6 | | | |

Table II

Initial Tensile Load Applied to Cylindrical Specimen

| Run No. | E_a | E_c | $\frac{E_{min}}{E_{max}}$ | E | D | %D | t | T_d | #stress-coat |
|----------------|-------|-------|---------------------------|-----|------|-------|----|-------|--------------|
| 23 | 638 | -195 | -.325 | 450 | -187 | -29.2 | 70 | 70.5 | 1207 |
| 24 | 652 | -175 | -.268 | 595 | -57 | -8.8 | 65 | 76.0 | 1208 |
| 27 | 642 | -182 | -.284 | 580 | -62 | -9.6 | 55 | 74.0 | 1207 |
| Average value: | | | -.293 | | | -15.9 | | | |

Table III

Axial Tensile Load Applied to Cylindrical Specimen
(Stresscoat on Specimen was Cracked)

| Run No. | E_a | E_c | $\frac{E_{min}}{E_{max}}$ | E | D | %D | t | T_d | #stress-coat |
|----------------|-------|-------|---------------------------|-----|-----|-------|----|-------|--------------|
| 25 | 568 | -179 | -.315 | 560 | -8 | -1.4 | 35 | 76.5 | 1208 |
| 26 | 675 | -185 | -.284 | 600 | -75 | -11.1 | 50 | 75.5 | 1208 |
| Average value: | | | -.300 | | | -6.2 | | | |

Table I

Table I

Internal Pressure Applied to Viscosity Section

| Run No. | Pressure (psi) | Viscosity (cP) | Temperature (°C) | Time (min) | Pressure (psi) | Viscosity (cP) | Temperature (°C) | Time (min) |
|---------|----------------|----------------|------------------|------------|----------------|----------------|------------------|------------|
| 17 | 300 | 335 | 30 | 10.1 | 300 | 335 | 30 | 10.1 |
| 18 | 300 | 335 | 30 | 10.1 | 300 | 335 | 30 | 10.1 |
| 19 | 300 | 335 | 30 | 10.1 | 300 | 335 | 30 | 10.1 |
| 20 | 300 | 335 | 30 | 10.1 | 300 | 335 | 30 | 10.1 |
| 21 | 300 | 335 | 30 | 10.1 | 300 | 335 | 30 | 10.1 |

Table II

Internal Pressure Applied to Viscosity Section

| Run No. | Pressure (psi) | Viscosity (cP) | Temperature (°C) | Time (min) | Pressure (psi) | Viscosity (cP) | Temperature (°C) | Time (min) |
|---------|----------------|----------------|------------------|------------|----------------|----------------|------------------|------------|
| 22 | 300 | 335 | 30 | 10.1 | 300 | 335 | 30 | 10.1 |
| 23 | 300 | 335 | 30 | 10.1 | 300 | 335 | 30 | 10.1 |
| 24 | 300 | 335 | 30 | 10.1 | 300 | 335 | 30 | 10.1 |
| 25 | 300 | 335 | 30 | 10.1 | 300 | 335 | 30 | 10.1 |

Table III

Internal Pressure Applied to Viscosity Section (Pressure on Section was 300 psi)

| Run No. | Pressure (psi) | Viscosity (cP) | Temperature (°C) | Time (min) | Pressure (psi) | Viscosity (cP) | Temperature (°C) | Time (min) |
|---------|----------------|----------------|------------------|------------|----------------|----------------|------------------|------------|
| 26 | 300 | 335 | 30 | 10.1 | 300 | 335 | 30 | 10.1 |
| 27 | 300 | 335 | 30 | 10.1 | 300 | 335 | 30 | 10.1 |

Table IV

Internal Pressure Applied To Cylindrical Specimen
After Crack Pattern Had Been Formed By Tensile Load.

| Run No. | E _a | E _c | $\frac{E_{min}}{E_{max}}$ | E | D | %D | t | T _d | #Stress- coat |
|----------------|----------------|----------------|---------------------------|-----|-----|-------|----|----------------|------------------|
| 23a | 134 | 592 | .227 | 510 | -82 | -13.8 | 25 | 70.5 | 1207 |
| 24a | 138 | 606 | .228 | 590 | -16 | - 2.6 | 25 | 76.0 | 1208 |
| 27a | 170 | 637 | .267 | 545 | -92 | -14.4 | 35 | 74.0 | 1207 |
| Average value: | | | .241 | | | -10.2 | | | |

Table V

Internal Pressure Applied To Cylindrical Specimen
After Crack Pattern Had Been Formed By Tensile Load.
(Stresscoat On Specimen Was Crazed)

| Run No. | E _a | E _c | $\frac{E_{min}}{E_{max}}$ | E | D | %D | t | T _d | #Stress- coat |
|----------------|----------------|----------------|---------------------------|-----|-----|------|----|----------------|------------------|
| 25a | 140 | 512 | .273 | 560 | 48 | 9.4 | 28 | 76.5 | 1208 |
| 26a | 131 | 633 | .207 | 608 | -25 | -4.0 | 35 | 75.5 | 1208 |
| Average value: | | | .240 | | | 2.7 | | | |

Table VI

Investigation Of Crazing And Its Effect On The
Sensitivity Of Stresscoat As Applied To The
Calibration Bars.

| Bar No. | Condition of Coat | Sensitivity 10 ⁻⁶ in/in. | Time Sec. | Temp. Fah. |
|---------|----------------------|--|--------------|---------------|
| 1 | clear | 680 | 30 | 72.5 |
| 2 | clear | 620 | 30 | 72.5 |
| 3 | clear | 630 | 30 | 72.5 |
| 4 | crazed | 780 | 30 | 72.5 |
| 5 | crazed | 820 | 30 | 72.5 |
| 6 | crazed | 850 | 30 | 72.5 |
| 7 | clear | 700 | 30 | 72.5 |
| 8 | clear | 630 | 1 | 72.5 |
| 9 | clear | 620 | 1 | 72.5 |
| 10 | clear | 600 | 1 | 72.5 |

Table IV

Internal Pressure Applied to Cylindrical Specimen
After Crack Pattern Had Been Formed by Tensile Load.

| Run No. | E_1 | E_2 | E_3 | E_4 | E_5 | E_6 | E_7 | E_8 | E_9 | E_{10} | Average value |
|---------|-------|-------|-------|-------|-------|-------|-------|-------|-------|----------|---------------|
| 278 | 170 | 637 | 545 | 592 | -14.4 | 35 | 74.0 | 1907 | | | |
| 248 | 138 | 606 | 590 | -16 | -2.2 | 35 | 76.0 | 1808 | | | |
| 258 | 134 | 595 | 570 | -82 | -11.8 | 35 | 70.2 | 1807 | | | |
| | | | | | | | | | | | -10.2 |

Table V

Internal Pressure Applied to Cylindrical Specimen
After Crack Pattern Had Been Formed by Tensile Load.
(Stresscoat on Specimen Was Traced)

| Run No. | E_1 | E_2 | E_3 | E_4 | E_5 | E_6 | E_7 | E_8 | E_9 | E_{10} | Average value |
|---------|-------|-------|-------|-------|-------|-------|-------|-------|-------|----------|---------------|
| 268 | 131 | 633 | 608 | -22 | -4.0 | 35 | 75.2 | 1808 | | | |
| 258 | 140 | 512 | 500 | 48 | 8.4 | 35 | 76.2 | 1808 | | | |
| | | | | | | | | | | | 5.7 |

Table VI

Investigation of Fracture and Its Effect on the
Sensitivity of Stresscoat as Applied to the
Cylindrical Bars.

| Bar No. | Condition of Coat | Sensitivity 10 ⁻³ in/in. | Time min. | Temp. deg. F. |
|---------|-------------------|-------------------------------------|-----------|---------------|
| 1 | clear | 680 | 30 | 75.2 |
| 2 | clear | 650 | 30 | 75.2 |
| 3 | clear | 670 | 30 | 75.2 |
| 4 | cracked | 760 | 30 | 75.2 |
| 5 | cracked | 820 | 30 | 75.2 |
| 6 | cracked | 650 | 30 | 75.2 |
| 7 | clear | 700 | 30 | 75.2 |
| 8 | clear | 670 | 1 | 75.2 |
| 9 | clear | 650 | 1 | 75.2 |
| 10 | clear | 600 | 1 | 75.2 |

Table VII

Summary of Biaxial Stress Conditions

| $\frac{E_{min}}{E_{max}}$ | $\frac{E_{min}/E_{max}}{e/E}$ | S_{min}/S_{max} | %D | %D _s | Run |
|---------------------------|-------------------------------|-------------------|--------|-----------------|----------|
| -1.0 | 3.39 | -1.0 | -24.4* | - 1.9 | Torsion |
| -0.295 | 1.00 | 0.0 | -15.9 | -15.9 | Tension |
| 0.25 | -0.849 | 0.5 | 10.6 | - 6.1 | Cylinder |
| 1.0 | -3.39 | 1.0 | 29.0* | - 9.9 | Sphere |

$$e/E = -.295/1 = -.295$$

* From Olsen's (11) data.

Table VII

Summary of Statistical Results

| | Mean | Standard Deviation | Standard Error | Minimum | Maximum |
|-------------|------|--------------------|----------------|---------|---------|
| Force | 1.0 | 0.25 | 0.25 | 0.0 | 2.0 |
| Temperature | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Humidity | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Pressure | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

$$e = -0.25 \sqrt{1} = -0.25$$

* From Table (II) data.

RESULTS

- (1) When perpendicular strains are in the ratio of 4 to 1, about 10% less strain is required to produce a crack pattern on the specimen than was indicated by the calibration bars. (See Table I)
- (2) When perpendicular strains are in the ratio of 3.4 to -1, about 16% more strain was required to produce a crack pattern on the specimen than was indicated by the calibration bars. (See Table II)
- (3) The presence of crazing in the Stresscoat prior to straining the coat to failure has a definite effect other than that of making the crack pattern difficult to observe.
 - a. Tests with several calibration bars indicate that the presence of crazing decreases the sensitivity of the coat about 25%. (See Table VI)
 - b. Actual experiments with the specimen indicate that crazing does decrease the sensitivity, however, too few experiments have been conducted to give an approximate percentage decrease in sensitivity.
(See Table III and Table V)
- (4) The presence of strain cracks in one direction prior to straining the coat to failure in a perpendicular direction has a definite effect on the sensitivity of the Stresscoat.
 - a. When perpendicular strains are in a ratio of 4 to 1 and straining to failure has been previously obtained

RESULTS

- (1) When perpendicular strains are in the ratio of 4 to 1, about 10% less strain is required to produce a crack pattern on the specimen than was indicated by the calibration bars. (See Table I.)
- (2) When perpendicular strains are in the ratio of 3.4 to 1, about 10% more strain was required to produce a crack pattern on the specimen than was indicated by the calibration bars. (See Table II.)
- (3) The presence of crazing in the stresscoat prior to strain- ing the coat to failure has a definite effect on the pattern of cracking. The crack pattern is difficult to observe. a. Tests with several calibration bars indicate that the presence of crazing increases the sensitivity of the coat about 25%. (See Table I.) b. Actual experiments with the specimens indicate that crazing does decrease the sensitivity. However, too few experiments have been conducted to give an approximate percentage decrease in sensitivity. (See Table III and Table V.)
- (4) The presence of strain cracks in one direction prior to strain- ing the coat to failure in a perpendicular direction has a definite effect on the sensitivity of the stresscoat. a. When perpendicular strains are in a ratio of 4 to 1, the strain to failure is about 25% less than that obtained

(4a) cont'.

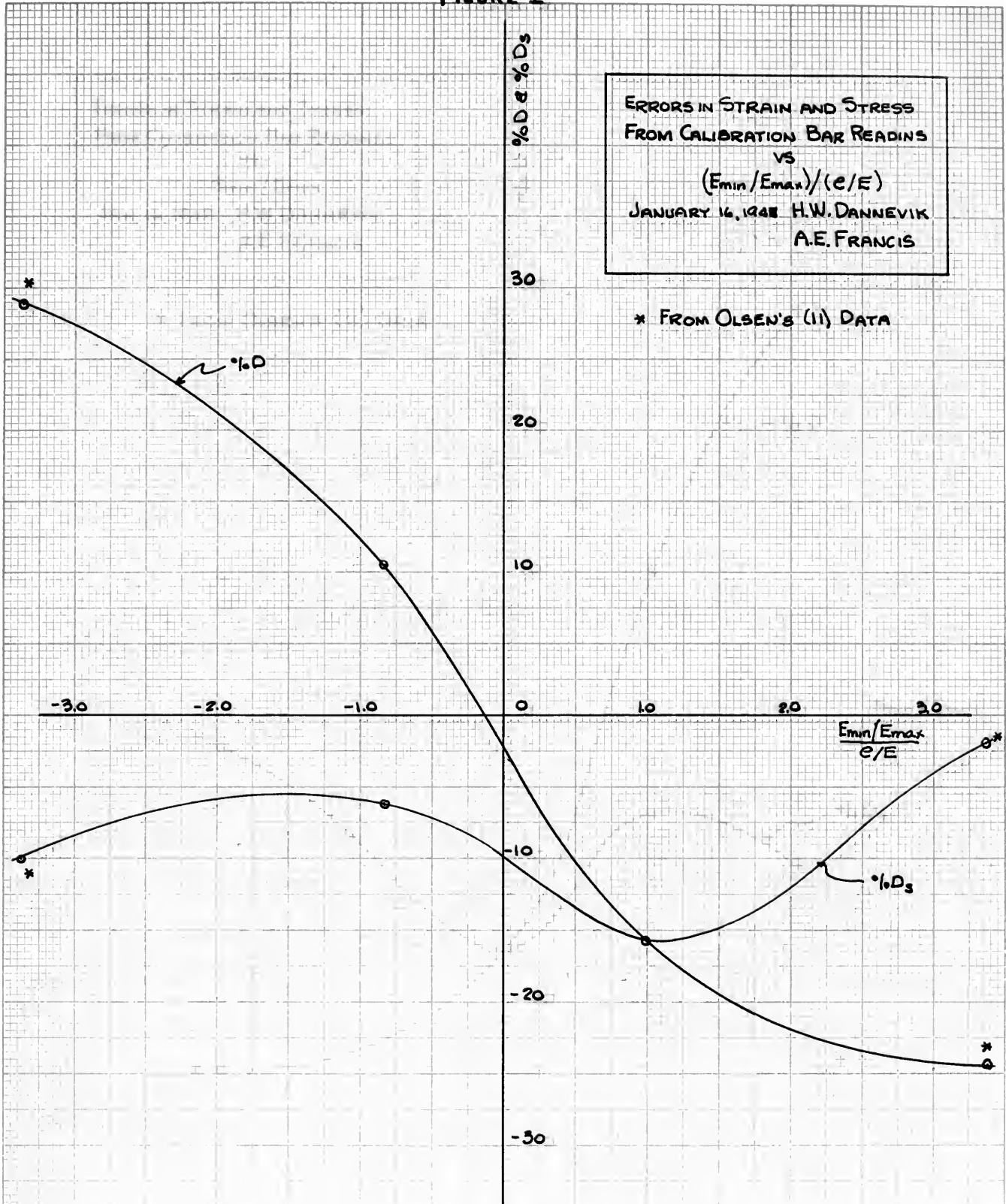
in the minor direction, it has been found that about 10% more strain is required to produce a crack pattern on the specimen than was indicated by the calibration bars. (See Table IV)

- b. Experiments, conducted with a 15 inch square piece of celluloid loaded as a cantilever beam to a certain deflection in one direction and then to the same deflection in the same length of time in a direction perpendicular to the first test, indicated that a crack pattern in one direction had little if any effect on the formation of a crack pattern at right angles to the original pattern. Of four tests made in this manner every one indicated identical sensitivity in either direction.

in the minor direction, it has been found that about 10% more strain is required to produce a crack pattern on the specimen than was indicated by the calibration data. (See Table IV)

d. Experiments, conducted with a 12 inch square piece of celluloid loaded as a cantilever beam to a certain deflection in one direction and then to the same deflection in the same length of time in a direction perpendicular to the first test, indicated that a crack pattern in one direction and little if any effect on the formation of a crack pattern at right angles to the original pattern. Of four tests made in this manner every one indicated identical sensitivity in either direction.

FIGURE I



ERRORS IN STRAIN AND STRESS
 FROM CALIBRATION BY RESONANCE
 vs
 STRAIN / STRESS
 JAN. 16, 1968 H.W. DANIELAK
 A.E. FRANCIS

* FROM OLSEN'S (II) DATA

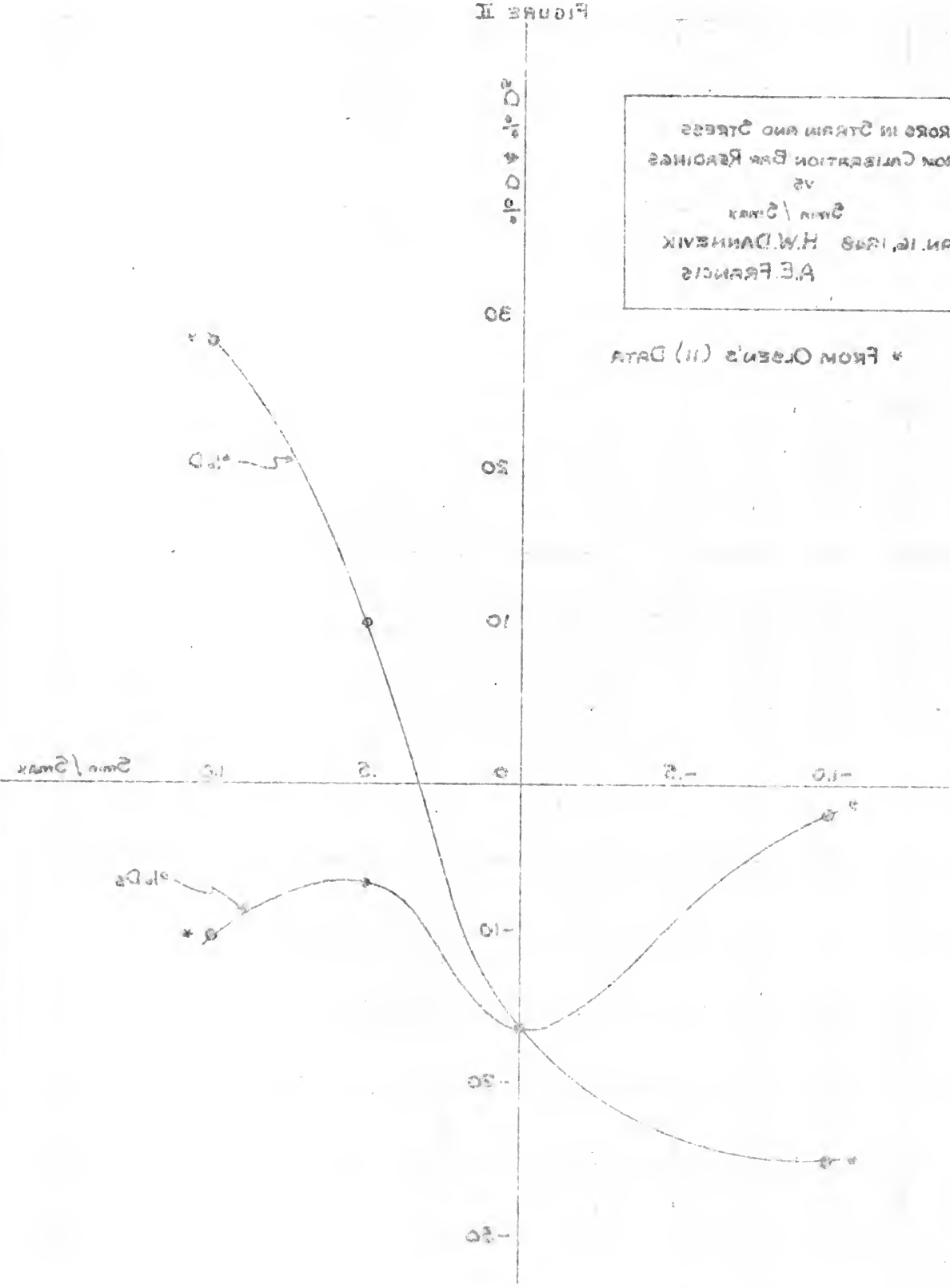


FIGURE II

DISCUSSION OF RESULTS

General

Conclusions concerning the overall trends of the behavior of Stresscoat are the only ones which can be drawn from the results which have been presented. The lack of facilities for controlling atmospheric conditions rendered it impossible to obtain even two identical runs. The temperature, humidity and grade of Stresscoat used were continuously varying throughout all runs. Therefore, it was impossible to compare the results of runs except for discerning a general picture. Results of specific comparison value can be obtained only by varying a single condition influencing the behavior of Stresscoat while other influencing agents are maintained constant. Desirable results may be obtained either by making all tests in a room where the temperature and humidity are controlled or by running such a large number of tests that the required number of identical runs occur by coincidence. Lack of facilities prevented using the former method and lack of time prevented using the latter.

Although Stresscoat used in the field by an experienced operator may in some cases give accuracy within the limits required by engineering practice, the desirability of spending much time on investigation of its behavior relative to the various elastic theories is questionable unless more adequate facilities for experimentation are made available.

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General

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Although Stresscoat used in the field by an experienced operator may in some cases give accuracy within the limits required by engineering practice, the desirability of spending much time on investigation of its behavior relative to the various of this product is questionable unless more accurate facilities for experimentation are made available.

The lack of temperature control also caused difficulty in maintaining equality of temperature between the specimen and the calibration bars, if the room temperature changed during the test. The difference in mass made the bars change in temperature much more quickly than the specimen did. This situation required artificial heating and cooling and often delayed runs annoyingly. The coatings, especially the more sensitive ones, were very susceptible to even small changes in temperature. A drop of two degrees in temperature may change the strain indicated by the lacquer of the order of one hundred micro inches.

No attempt was made to correlate stress with strain for any one run. The length of the specimen tended to reduce any deviation from pure axial loading during the tensile runs, but the slight disagreement between diametrically opposite strain gauges indicated some angularity of loading or local discontinuity of wall thickness. A slight discrepancy in strain gauge readings was also present during pressure runs. This disagreement was probably due to the bending of the specimen in the cradle, as the cracks in the coating appeared first on the bottom of the specimen, where the wall was subjected to tensile bending stress in addition to the stress from internal pressure. These conditions and some variance in the position of the specimen during the successive tests account for the occurrence of different strains in one direction when the strains in the perpendicular

The lack of temperature control also caused difficulty in maintaining equality of temperature between the specimen and the calibration bars, if the room temperature changed during the test. The difference in mass made the bars change in temperature much more quickly than the specimen did. This situation required artificial heating and cooling and often delayed runs unduly. The containers, especially the more sensitive ones, were very susceptible to even small changes in temperature. A drop of two degrees in temperature may change the strain indicated by the location of the rider of one hundred micro inches. No attempt was made to correlate stress with strain for any one run. The length of the specimen tended to reduce any deviation from pure axial loading during the tensile runs, but the slight displacement between diametrically opposite strain gauges indicated some angularity of loading or local discontinuity of wall thickness. A slight discrepancy in strain gauge readings was also present during pressure runs. This displacement was probably due to the bending of the specimen in the grips, as the cracks in the coating appeared first on the inner or the outer, where the wall was subjected to tensile bending stress in addition to the stress from internal pressure. These conditions and some variance in the position of the specimen during the successive tests account for the occurrence of different strains in one direction when the strains in the perpendicular

direction were equal. Consequently, strains, computed from the loading and specimen dimensions, erred from actual strains observed in the specimen by as much as ten percent. The magnitude of strain was obtained independently by the strain gauges. The values of axial load and internal pressure were used merely as an aid in applying the load uniformly.

Two-Dimensional Strain

The results obtained, combined with information determined by Olsen (11), give a rough overall picture of how the magnitude of the deviation of the calibration bar strain from the actual strain varies as the ratio of the two-dimensional strain varies from positive to negative unity. The internal pressure tests of this report $E_{\min}/E_{\max} = .25$ and the Olsen (11) hollow sphere test $E_{\min}/E_{\max} = 1.0$ indicated that as the ratio of E_{\min}/E_{\max} increases in a positive direction the amount of strain necessary to cause failure in the coating on the specimen becomes progressively less than that indicated by the calibration bars. Olsen's (11) pure torsion test $E_{\min}/E_{\max} = -1.0$ indicates that as the ratio of E_{\min}/E_{\max} approaches negative unity the strain necessary to cause failure in the coating on the specimen becomes progressively greater than the strain indicated by the calibration bar.

A positive theoretical explanation for the behavior of Strescoat described above was not attained. However, a possible explanation has been developed, but it depends on the following two assumptions for validity:

direction were equal. Consequently, strains, computed from the loading and specimen dimensions, varied from actual strains observed in the specimen by as much as ten percent. The magnitude of strain was obtained independently by the strain gauges. The values of axial load and internal pressure were used merely as an aid in applying the load uniformly.

Two-Dimensional Strain

The results obtained, combined with information determined by Class (II), give a rough overall picture of the magnitude of the deviation of the calibration bar strain from the actual strain varies as the ratio of the two-dimensional strain varies from positive to negative unity. The internal pressure tests of this report $\epsilon_{min}/\epsilon_{max} = .75$ and the Class (II) hollow sphere test $\epsilon_{min}/\epsilon_{max} = 1.0$ indicated that as the ratio of $\epsilon_{min}/\epsilon_{max}$ increases in a positive direction the amount of strain necessary to cause failure in the coating on the specimen becomes progressively less than that indicated by the calibration bar. Class's (II) sphere tension test $\epsilon_{min}/\epsilon_{max} = -1.0$ indicates that as the ratio of $\epsilon_{min}/\epsilon_{max}$ approaches negative unity the strain necessary to cause failure in the coating on the specimen becomes progressively greater than the strain indicated by the calibration bar. A positive theoretical explanation for the behavior of stresses described above was not attained. However, a possible explanation has been developed, and it depends on the following two assumptions for validity.

(1) The stress in the coating is due to the strain in the base material and has no direct connection with the load on the specimen.

(2) Stresscoat fails in tension according to the Maximum Stress Theory.

When E_{min}/E_{max} is positive the Poisson effect of E_{min} tends to shorten the coating in the E_{max} direction. Each point in the coating is restrained by the surrounding lacquer so a tensile stress is induced in the E_{max} direction. Therefore, less direct tension is required to produce failure than if the tension induced due to E_{min} did not exist and the coating fails at a strain lower than that indicated by the calibration bar. When E_{min}/E_{max} is negative the Poisson effect of E_{min} tends to lengthen the coating in the E_{max} direction and a compression stress is induced in the lacquer in the E_{max} direction. For failure to occur in the coat, an amount of tension sufficient to overcome the induced compression is necessary in addition to the normal direct tension required for coat failure if the induced compression were not present. Consequently, the coat fails at a higher value of strain than indicated by the calibration bar. Both Olsen (11) and Durelli (14) experienced difficulty in producing failure in the coating, due to Poisson's effect only, in a direction perpendicular to a compression load. Such behavior of the lacquer conforms to the above theory.

Calibration

According to theory an element on the surface of a

specimen loaded with axial tension only and an element on the top of a loaded cantilever beam are both subjected to the same pattern of two-dimensional strain. In the tension runs the ratio E_{min}/E_{max} was equal to Poisson's ratio as expected; therefore, the disagreement between the actual strain causing failure and the strain indicated by the calibration bar was puzzling. The actual strain required to cause failure of the coating on the specimen was about 15% greater than that indicated by the calibration bar.

A check was made to insure that the calibration bar conformed to beam theory and Poisson's effect, and the results were positive. Further thought has made apparent a possible explanation for the disagreement described above. The thickness of the coat on the calibration bar is an appreciable fraction of the distance from the neutral axis to the outer surface of the bar. Consequently, the strain at the outer surface of the coating is greater than the actual strain on the bar surface underneath. Since the calibration frame is graduated in strain on the bar surface and the cracks initiate on the outer surface of the coat, the strain initiating the cracks is greater than that indicated by the calibration bar. When a specimen is under axial load the strain throughout the coating is the same as that on the surface of the specimen. The assumption that the strain in the outer surface of the bar coating and the strain in the tensile specimen were approximately the same accounts for the discrepancies observed. In contrast to the case of the calibration bar, during tensile runs the cracks were observed

specimen loaded with axial tension only and an element on the top of a loaded cantilever beam are both subjected to the same pattern of two-dimensional strain. In the tension tests the ratio $\epsilon_{\text{max}}/\epsilon_{\text{min}}$ was equal to Poisson's ratio as expected; therefore, the disagreement between the actual strain causing failure and the strain indicated by the calibration bar was puzzling. The actual strain required to cause failure of the coating on the specimen was about 15 percent less than that indicated by the calibration bar.

A check was made to insure that the calibration bar conformed to beam theory and Poisson's effect, and the results were negative. Further thought was made regarding a possible explanation for the disagreement described above. The thickness of the coat on the calibration bar is an average of the thickness of the distance from the neutral axis to the outer surface of the bar. Consequently, the strain at the outer surface of the coating is greater than the actual strain on the bar surface underneath. Since the calibration frame is positioned in strain on the bar surface and the cracks initiate on the outer surface of the coat, the strain indicated by the cracks is greater than that indicated by the calibration bar. That a specimen is under axial load the strain throughout the coating is the same as that on the surface of the bar. The average strain on the coating is the average strain on the bar coating and one at the surface. The results were accordingly the same as those for the calibration bar. In contrast to the case of the calibration bar, during tension tests the cracks were observed

to originate on the surface of the base material and then spread outward through the coat.

Olsen's tensile investigation strengthens the theory presented above. The deviations he obtained compare favorably in magnitude and sign with those observed in this experiment. He commented on the inaccuracy of calibration but did not attach any significance to the fact that in each of his runs the calibration bar indicated strains less than those actually present.

The experience of Olsen and the authors suggest that there is an inherent error in strains indicated by the calibration bar except where the specimen is loaded in a condition of bending similar to that in the bar. This error is independent of that due to a particular condition of two-dimensional strain in the specimen.

Curves

In figures 1 and 2 the errors in strain and stress encountered when using the calibration bar are plotted as functions of S_{min}/S_{max} and $\frac{E_{min}}{E_{max}}$. During the tensile run the two-dimensional strain systems are the same in the specimen and the bar and the only error is the inherent error due to coat thickness which is always present when using the calibration bar. As far as stress is concerned this error, occurring alone for the condition of uniaxial stress, is the maximum error ever present. Evidently the error brought in due to the difference in the two-dimensional

to orientate on the surface of the base material and then spread outward through the coat.

Cleese's tensile investigation demonstrates the theory presented above. The deviations are obtained on the favorably in magnitude and sign with those observed in this experiment. He commented on the lack of accuracy of calibration but did not attach any significance to the fact that in each of his runs the calibration bar indicated strains less than those actually present.

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Curves

In Figures 1 and 2 the errors in strain and stress encountered when using the calibration bar are plotted as functions of $\frac{\sigma}{\sigma_{max}}$ and $\frac{\epsilon}{\epsilon_{max}}$. Using the tensile run the two-dimensional strain ϵ_{2D} and the error in the specimen and the bar and the only error in the specimen error due to the fact that the specimen which is always present when using the calibration bar. As far as stress is concerned the error, occurring along for the condition of material stress, is the maximum error ever present. Evidently the error shown in due to the difference in a two-dimensional

strain system in the specimen and the bar and the inherent error tend to be compensating and reduce the total error in stress determination. When strain is the important consideration it is noted that the maximum error occurs at the extremities of the possible $\frac{E_{min}/E_{max}}{e/E}$ range. For strain determinations the point where one error completely compensates for the other error occurs where S_{min}/S_{max} has a value of about .25. The seriousness of these errors depends on the experimental error probable for the conditions of the test and the accuracy required.

Effect of Existing Cracks on Failure in Another Direction

When pressure runs were made after a tensile crack pattern had been previously obtained the calibration bar indicated less strain than that actually required to cause failure on the specimen. This occurrence, which is just opposite to that observed for initial pressure runs, was not satisfactorily understood. The circumferential closely spaced cracks already present eliminate the axial restraint normally present in an intact coating. This condition combined with the possibility of a creep effect (the technique claimed to eliminate creep by the manufacturer was always used) are the only apparent factors which may contribute to the peculiar behavior of the coating.

An attempt to gain further insight into this problem was made by experimenting with the flat celluloid plate. The results, indicating that cracks in one direction do not

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Effect of Extending Cracks on Failure in Another Direction

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An attempt to gain further insight into this problem was made by experimentation with the flat calibration plate. The results, indicating that cracks in one direction do not

influence cracking in the other perpendicular direction, did not increase the understanding of the situation. However, cracks on the edges of the crack patterns on the plate were farther apart, shorter and less well developed than the cracks which extended over the whole specimen.

Crazing

The runs made specifically to investigate the effect of crazing and those pressure and tensile runs where unintentional crazing occurred prior to the run, both indicated that the presence of crazing substantially decreases the sensitivity of the coating as well as making the initial cracks difficult to see. (As the sensitivity of the coating increases it fails at a lower value of strain). The error induced probably varies directly with the intensity of crazing. The more sensitive coats were more susceptible to crazing. The occurrence of crazing depended on the minimum temperature experienced prior to testing and also the rate of fall of the temperature. Even small changes in temperature caused crazing if the change was swift enough. Decreases in temperature caused stresses in the coating due to different thermal coefficients of expansion in the Stresscoat and the material underneath, which are finally relieved by crazing of the coating. After crazing has occurred much of the restraint in the coating at a local point due to the presence of the surrounding coating has been eliminated. When crazing occurred on bars which already contained a crack

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pattern intense crazing occurred only on the uncracked portion and extended only from crack to crack. It is of interest to note that crazing decreased the sensitivity of a coat about 25% while the strain which produced failure in the pressure runs following a tensile run was 25% greater than the strain producing failure in an initial pressure run. Temperature change craze should not be confused with drying craze which usually does not present a problem.

Accuracy

The effect of creep is pronounced and should not be underestimated. A slight deviation was present between results obtained by loading the calibration bar in the same time as the specimen, and by using the creep correction chart supplied by the manufacturer and loading the bar in one second. However, this deviation was inconsistent in sign and probably was due to normal experimental error.

Most of the published material concerning the use of Stresscoat, except the manufacturer's detailed instructions, underestimate the difficulties which will be encountered in using Stresscoat when atmospheric conditions are not controllable.

A consideration of the accuracy with which a calibration bar may be read indicates that the maximum error likely is less than 10%. Olsen (11) found the same accuracy possible in reading calibration bars.

pattern intense crazing occurred only on the uncracked portion and extended only from crack to crack. It is of interest to note that crazing decreased the sensitivity of a test about 25% while the strain which produced failure in the pressure runs following a tensile run was 25% greater than the strain producing failure in an initial pressure run. Temperature change alone should not be confused with drying crazes which usually does not present a problem.

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A consideration of the accuracy with which a calibration bar may be read indicates that the maximum error likely is less than 10%. Class (II) found the same accuracy possible in reading calibration bars.

Future Work

It is desirable that the behavior of Stresscoat be investigated for other conditions of biaxial stress in addition to those covered by this report. This additional information would confirm or disprove the shape of the curves of Figures 1 and 2. An attempt to obtain failure of the coat at other ratios of E_{min}/E_{max} was made but the uniform application of internal pressure and axial load simultaneously, which is required due to the creep characteristics of the coating, was impossible with the experimental set-up and the personnel available. The production of apparatus to accomplish this should not be difficult. The use of a small specimen is recommended.

The Poisson's ratio and the modulus of elasticity of Stresscoat itself are important characteristics, the determination of which will allow further insight into the behavior of Stresscoat. With controlled atmospheric conditions it will be possible to limit a series of runs to one grade of Stresscoat. If the Poisson's ratio and the modulus of elasticity for a particular grade of Stresscoat are known, together with the principal strains existing at failure over the possible range of biaxial stress conditions, the actual stress in the coating at failure can be determined. The values of such stresses can be employed to ascertain the theory of failure which Stresscoat follows.

It is desirable that the behavior of stress-strain be investigated for other conditions of biaxial stress in addition to those covered by this report. The additional information would confirm or disprove the shape of the curves of Figures 1 and 2. An attempt to obtain failure of the coat at other ratios of $\epsilon_{min}/\epsilon_{max}$ was made but the uniform application of internal pressure and axial load simultaneously, which is required due to the stress characteristics of the coating, was impossible with the experimental set-up and the personnel available. The production of a coating to accomplish this should not be difficult. The use of a small specimen is recommended.

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Summation

The discussions presented have been based on averages of several runs. Although the spread of results for each series of similar runs was quite wide, all the results for each series of runs were of the same sign. After considering the unfavorable conditions under which the investigations were made it is felt that the consistency of the results obtained, and the favorable comparison with Olsen's (11) work, have allowed the authors to present a reasonably accurate overall picture.

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CONCLUSIONS

1. If results of theoretical value are to be obtained from experimenting with Stresscoat the experiments must be conducted in a controlled atmosphere.
2. The presence of biaxial stresses in a specimen under investigation and the consequent difference between the two-dimensional strain systems in the specimen and the calibration bar cause the strain indicated by the calibration bar to err from that strain causing failure in the Stresscoat on the specimen. The magnitude and direction of this deviation varies, as the ratio of minimum to maximum strain in the specimen changes from the corresponding ratio in the calibration bar.
3. When the specimen under investigation is loaded in a different manner than the calibration bar the strain indicated by the calibration bar is in error.
4. For stress determinations the two errors above are compensating and the total error is a maximum when the inherent calibration bar error is the only one present.
5. For strain determinations the maximum positive and negative errors occur at the extremities of the $\frac{E_{min}/E_{max}}{e/E}$ and S_{min}/S_{max} ranges. Somewhere within the extremities there is a point of no error.
6. Crazeing affects the sensitivity of Stresscoat. The presence of previously obtained crack pattern affects the sensitivity of the coating to cracking in another direction.

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4. For stress determinations the two errors above are compensating and the total error is a maximum when the inherent calibration bar error is the only one present.
5. For strain determinations the maximum positive and negative errors occur at the extremities of the $\frac{\epsilon_{min}}{\epsilon_{max}}$ and $\frac{\epsilon_{max}}{\epsilon_{min}}$ ratios. Somewhere within the extremes there is a point of no error.
6. Strain affects the sensitivity of stresscoat. The presence of a very closely spaced crack pattern affects the sensitivity of the coating to strain in and out of direction.

RECOMMENDATIONS

1. If further investigation in the field of strain indicating brittle lacquer is undertaken, facilities for experimenting under controlled atmospheric conditions should be supplied.
2. Further investigation of the behavior of Stresscoat when subjected to biaxial stress should be made under controlled atmospheric conditions and for more ratios of S_{min}/S_{max} .
3. The Poisson's ratio and modulus of elasticity and then the theory of failure of Stresscoat should be determined.
4. An investigation of the causes and affects of crazing on the behavior of Stresscoat should be made.

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APPENDIX

APPENDIX

APPENDIX A
DETAILS OF PROCEDURE

Description of Apparatus

Specimen

The body of the specimen was a drawn seamless tube. The outside diameter was $4\frac{1}{2}$ inches and the wall thickness was .140 inches. The material conformed with Navy Specification N-44-T-13, Cat. No. 1077, 44-T-5450-10. The composition was .25% carbon, .70% Manganese, .04% Phosphorous, and .04% Sulphur. The yield point was 35,000 psi and the ultimate strength was 60,000 psi. The length of the body was 30 inches.

The ends were machined from rough steel forgings. The inner extremities of the ends were machined to fit snugly into the tube for a distance of two inches. The outer extremities were turned down to two inches in diameter and then drilled and tapped with a $1\frac{1}{2}$ inch, 7 threads per inch tap. The end pieces were secured to the body by both fillet and plug welds.

Each end of the specimen was fitted with a 6,000 psi valve. One end was connected to the pump through a portable section of high pressure copper tubing by means of two heavy duty unions.

Strain Gauges and Strain Indicator

The SA-4 strain gauges were bonded resistance wire type strain gauges manufactured by the Baldwin Outwork

Description of Specimen

Specimen

The body of the specimen was a single cylindrical tube. The outside diameter was 4 1/2 inches and the wall thickness was .140 inches. The material contained with heavy metal-lic was 140 inches. The material was 100% carbon. The composition was .99% carbon, .01% manganese, .04% phosphorus, and .04% sulfur. The yield point was 110,000 psi and the ultimate strength was 80,000 psi. The length of the body was 10 inches.

The ends were machined from tough steel forgings. The inner extremities of the ends were machined to fit snugly into the tube for a distance of 1/2 inch. The outer extremities were turned down to two inches in diameter and then drilled and reamed with a 1/2 inch. The threads were 1 inch long. The end pieces were secured to the body by bolt flanges and girth rings.

One end of the specimen was fitted with a 1/2 inch diameter valve. The end was connected to the pump through a vertical section of high pressure copper tubing by means of two heavy duty unions.

Test Results and Specimen Information

No test results were obtained. The specimen was destroyed during the test.

Division, Baldwin Locomotive Works. The specific type gauge used was an A-3, 13/16 inch gauge length, 120 ohm, and with a gauge factor of 2.03. The strain readings were obtained by the use of an SR-4 Strain Gauge Indicator, also manufactured by Baldwin.

Testing Machine

The tensile loading machine that was used was a Riehle Tensile Testing Machine, No. 214, having a maximum load capacity of 100,000 lbs. It was located in the Material Test Laboratory, Massachusetts Institute of Technology.

Hydraulic Pump

The pump used was a 10,000 lb. capacity hydraulic pump, a type sometimes used as a jack.

Division, Baldwin Locomotive Works. The specific type gauge used was an A-2, 15/16 inch gauge length, 150 mm, and with a gauge factor of 5.00. The strain gauges were obtained by the use of an A-4 strain gauge indicator, also manufactured by Baldwin.

Tensile Machine

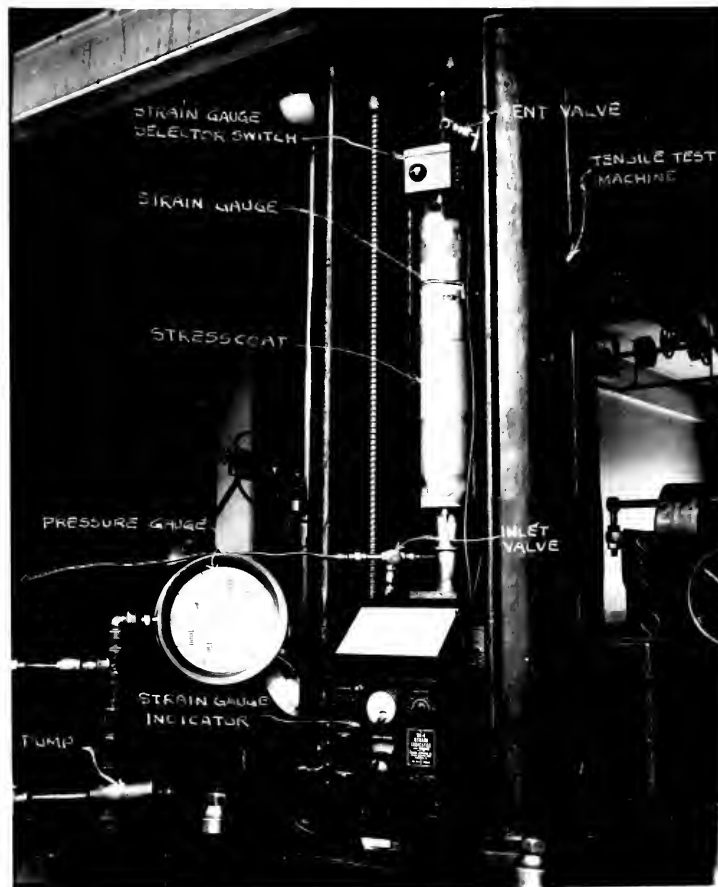
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Hydraulic Press

The press used was a 10,000 lb. capacity hydraulic press, a type sometimes used as a jack.



Experimental Specimen



Experimental Arrangement

Experimental Section

APPENDIX B

SAMPLE CALCULATIONS

Correction for Lateral Sensitivity of SR-4 Strain Guage

The corrections for lateral sensitivity were made as outlined in reference (15). SR-4 strain guages are calibrated for uniaxial stress along the axis, on steel having a Poisson's ratio, ν , of .285. In any case involving two guages at right angles, if the conditions of strain under which the guages were calibrated are given, it is possible to find the true strains by the two simultaneous equations:

$$E_{\max} = \frac{(1 - \nu_0 K)(e_{\max} - K e_{\min})}{(1 - K^2)}$$

$$E_{\min} = \frac{(1 - \nu_0 K)(e_{\min} - K e_{\max})}{(1 - K^2)}$$

Where symbols have meanings shown by Table of Symbols.

Typical Pressure Run (No. 17) $t = 225$ seconds.

$$e_a = (230 + 220)/2 = 225 \quad e_c = (850 + 840)/2 = 845$$

$$E_a = \frac{[1 - (.285)(.021)][225 - (.021)(845)]}{[1 - (.021)^2]} = 206 = E_{\min}$$

$$E_c = \frac{[1 - (.285)(.021)][845 - (.021)(225)]}{[1 - .021^2]} = 835 = E_{\max}$$

$$E_a/E_c = E_{\min}/E_{\max} = 206/835 = .247$$

TABLE 3 SAMPLE CALCULATIONS

Correction for lateral sensitivity of SR-4 strain gauges

The correction for lateral sensitivity were made as outlined in reference (12). SR-4 strain gauges are calibrated for uniaxial stress along the axis, on steel having a Poisson's ratio, ν , of .285. In any case involving two gauges at right angles, if the conditions of strain under which the gauges were calibrated are given, it is possible to find the true strains by the two simultaneous equations:

$$E_{max} = \frac{(1 - \nu K)(\epsilon_{max} - K\epsilon_{min})}{(1 - K^2)}$$

$$E_{min} = \frac{(1 - \nu K)(\epsilon_{min} - K\epsilon_{max})}{(1 - K^2)}$$

where symbols have meanings shown by Table of Symbols.

Typical pressure run (No. 17) $t = 225$ seconds.

$$\epsilon_c = (520 + 550) / 2 = 535 \quad \epsilon_c = (820 + 840) / 2 = 830$$

$$E_c = \frac{[1 - (.582)(.051)] [535 - (.051)(830)]}{[1 - (.051)^2]} = 506 = E_{min}$$

$$E_c = \frac{[1 - (.582)(.051)] [830 - (.051)(535)]}{[1 - (.051)^2]} = 832 = E_{max}$$

$$E_c / E_c = E_{min} / E_{max} = 506 / 832 = .607$$

APPENDIX B
SAMPLE CALCULATIONS

For Calibration bar loaded in 225 seconds.

$$E = (920 + 920 + 860) / 3 = 900$$

$$E - E_c = 900 - 835 = 65$$

$$\%D = (100)(65) / (835) = 7.7\%$$

For calibration bar loaded in 1 second and creep corrected.

$$E = (1000 + 960 + 1000) / 3 = 987$$

Typical Tensile Run (No. 23) t = 70 seconds

$$e_a = (655 + 620) / 2 = 638 \quad e_c = (-210 - 180) / 2 = -195$$

$$E_a = \frac{[1 - (.285)(.021)][638 - (.021)(-195)]}{[1 - (.021)^2]} = 637 = E_{max}$$

$$E_c = \frac{[1 - (.285)(.021)][-195 - (.021)(638)]}{[1 - (.021)^2]} = -207 = E_{min}$$

$$E_c / E_a = E_{min} / E_{max} = -207 / 637 = -.325$$

For calibration bar loaded in 70 seconds.

$$E = 450 \quad E - E_a = 450 - 637 = -187$$

$$\%D = (100)(-187) / (637) = -29.4\%$$

10-11-12

10-11-12

For calibration bar loaded in 250 pounds.

$$E = (420 + 420 + 840) / 3 = 400$$

$$E - E_c = 400 - 832 = 42$$

$$\% D = (100)(42) / (832) = 5.1\%$$

For calibration bar loaded in 1000 and over pounds.

$$E = (1000 + 420 + 1000) / 3 = 887$$

Typical results for 1000 lb. bar

$$E_c = (422 + 420) / 2 = 421$$

$$E_{max} = E_{work} = 421 = \frac{[1 - (.001)(.001)] [422 - (.001)(-12)]}{[1 - (.001)^2]}$$

$$E_c = \frac{[1 - (.001)(.001)] [422 - (.001)(-12)]}{[1 - (.001)^2]} = -501 = E_{min}$$

$$E_c / E_c = E_{min} / E_{work} = -501 / 421 = -1.19$$

For calibration bar loaded in 1000 lb.

$$E = 420 \quad E - E_c = 420 - 421 = -1$$

$$\% D = (100)(-1) / (421) = -0.24\%$$

APPENDIX B
SAMPLE CALCULATION

For calibration bar loaded in 1 second and creep corrected.

$$E = (580 + 430 + 560)/3 = 523$$

Stress Calculations

For the calibration bar case.

$$S_{max} = \frac{E_m(E + \nu e)}{(1 - \nu^2)} \quad e = -.295E = -\nu E$$

$$S_{max} = \frac{E_m(E - \nu^2 E)}{1 - \nu^2} = \frac{E_m(1 - \nu^2)E}{1 - \nu^2} = E_m E$$

For the cylinder under internal pressure.

$$E_{min} = .25E_{max} \quad E_{max} = .905 E$$

$$\begin{aligned} S_{max} &= \frac{E_m(E_{max} + \nu E_{min})}{(1 - \nu^2)} = \frac{E_m[E_{max} + (.295)(.25)E_{max}]}{.913} \\ &= \frac{(1.0738)(E_m E_{max})}{.913} = \frac{(1.0738)(.905)E_m E}{.913} = 1.064 E_m E \end{aligned}$$

$$\% D_s = (100)(1 - 1.064)/(1.064) = -6.1\%$$

The calculations for the cases of pure torsion, axial load, and the sphere under internal pressure are similar to those above.

For calibration per load in 1 second and other conditions.

$$E = (280 + 430 + 250) \times 3 = 255$$

Stress Calculations

For the calibration per stress.

$$S_{max} = \frac{E_M(E + V_E)}{(1 - V_E)} \quad S = -0.242E = -VE$$

$$S_{max} = \frac{E_M(E - V_E)}{1 - V_E} = \frac{E_M(1 - V_E)E}{1 - V_E} = E_M E$$

For the cylinder under internal pressure.

$$E_{min} = 0.52E_{max} \quad E_{max} = 0.02E$$

$$S_{max} = \frac{E_M(E_{max} + V_{E_{min}})}{(1 - V_E)} = \frac{E_M[E_{max} + (0.52)(0.02)E_{max}]}{0.13}$$

$$= \frac{(1.0138)(E_M E_{max})}{0.13} = \frac{(1.0138)(0.02)(0.02)E_M E}{0.13} = 1.044E_M E$$

$$P.D. = (100)(1 - 1.044)(1.044) = -0.14$$

The calculations for the stress in the cylinder are as follows, and the results are shown in the table below.

APPENDIX C
ORIGINAL DATA

SECRET
NOFORN

| | | |
|--------------------------|--------------------|-------------|
| Test #17 | <u>Application</u> | <u>Test</u> |
| Date | 5 Dec 1947 | 6 Dec 1947 |
| Time | 1300 | 1000 |
| Wet Bulb | 50.5° F | 50° F |
| Dry Bulb | 71° F | 66° F |
| #Stresscoat Used | #1204 | #1204 |
| #Stresscoat Called For | #1202 | #1201 |
| Time of Loading Specimen | | 225 sec |

Specimen Temp. at time of coat failure: 70.5° F

| <u>Internal Pressure</u> <u>psi gage</u> | <u>Axial Load</u> <u>Lbs.</u> | <u>Strain Gage (micro inches)</u> | | | |
|---|----------------------------------|-----------------------------------|------|------|------|
| | | 1 | 2 | 3 | 4 |
| 0 | 0 | 420 | 250 | 850 | 180 |
| | | #8 ref | #4 | #5 | #7 |
| 2100 | 0 | 650 | 1100 | 1070 | 1020 |
| | | #8 | #4 | #5 | #7 |
| 0 | 0 | 455 | 250 | 840 | 175 |
| | | #8 | #4 | #5 | #7 |

| | | | | | | |
|----------------------------|------|------|------|------|------|------|
| Calibration Bar No. | 1 | 2 | 3 | 4 | 5 | 6 |
| Strain, Micro Inches | 780 | 750 | 920 | 920 | 780 | 860 |
| Time of Loading Bar, Secs. | 1 | 1 | 225 | 225 | 1 | 225 |
| Bar Temperature, degrees F | 70.5 | 70.5 | 70.5 | 70.5 | 70.5 | 70.5 |

| Test No. | Time | Net Sulf | Dry Sulf | Strassburg Used | Strassburg Called for | Time of Loading Specimen | Specimen Temp. at time of test (Fahrenheit) | Internal Pressure (psi) | Internal Load (lbs.) | Calibration Bar No. | Strain, after loading | Time of loading (sec.) | Bar Temperature, degrees |
|----------|------|----------|----------|-----------------|-----------------------|--------------------------|---|-------------------------|----------------------|---------------------|-----------------------|------------------------|--------------------------|
| 1 | 10.0 | 1000 | 1000 | 1504 | 1504 | 1501 | 70.5 | 0 | 0 | 1 | 100 | 10.0 | 70.5 |
| 2 | 10.0 | 1000 | 1000 | 1504 | 1504 | 1501 | 70.5 | 0 | 0 | 2 | 100 | 10.0 | 70.5 |
| 3 | 10.0 | 1000 | 1000 | 1504 | 1504 | 1501 | 70.5 | 0 | 0 | 3 | 100 | 10.0 | 70.5 |
| 4 | 10.0 | 1000 | 1000 | 1504 | 1504 | 1501 | 70.5 | 0 | 0 | 4 | 100 | 10.0 | 70.5 |
| 5 | 10.0 | 1000 | 1000 | 1504 | 1504 | 1501 | 70.5 | 0 | 0 | 5 | 100 | 10.0 | 70.5 |
| 6 | 10.0 | 1000 | 1000 | 1504 | 1504 | 1501 | 70.5 | 0 | 0 | 6 | 100 | 10.0 | 70.5 |
| 7 | 10.0 | 1000 | 1000 | 1504 | 1504 | 1501 | 70.5 | 0 | 0 | 7 | 100 | 10.0 | 70.5 |
| 8 | 10.0 | 1000 | 1000 | 1504 | 1504 | 1501 | 70.5 | 0 | 0 | 8 | 100 | 10.0 | 70.5 |
| 9 | 10.0 | 1000 | 1000 | 1504 | 1504 | 1501 | 70.5 | 0 | 0 | 9 | 100 | 10.0 | 70.5 |
| 10 | 10.0 | 1000 | 1000 | 1504 | 1504 | 1501 | 70.5 | 0 | 0 | 10 | 100 | 10.0 | 70.5 |

| <u>Test #18</u> | <u>Application</u> | <u>Test</u> |
|--------------------------|--------------------|-------------|
| Date | 6 Dec 1947 | 7 Dec 1947 |
| Time | 1100 | 1000 |
| Wet Bulb | 50° F | 52° F |
| Dry Bulb | 66° F | 70.5° F |
| #Stresscoat Used | #1204 | #1204 |
| #Stresscoat Called For | #1201 | |
| Time of Loading Specimen | | 120 sec |

Specimen Temp. at time of coat failure: 69° F

| Internal Pressure psi gage | Axial Load Lbs. | <u>Strain Gage (micro inches)</u> | | | |
|----------------------------------|-----------------------|-----------------------------------|------|------|------|
| | | 1 | 2 | 3 | 4 |
| 0 | 0 | 505 | 415 | 1185 | 340 |
| | | #8 ref | #4 | #5 | #7 |
| 1925 | 0 | 750 | 1210 | 1370 | 1120 |
| | | #8 | #4 | #5 | #7 |

| | | | | | | |
|----------------------------|-----|-----|-----|-----|------|-----|
| Calibration Bar No. | 1 | 2 | 3 | 4 | 5 | 6 |
| Strain, Micro Inches | 680 | 950 | 700 | 905 | 1010 | 800 |
| Time of Loading Bar, Secs. | 1 | 120 | 1 | 120 | 120 | 1 |
| Bar Temperature, degrees F | 69 | 69 | 69 | 69 | 69 | 69 |

Remarks:

It was necessary to cool bars and specimen to obtain sensitivity of practical value. A marked variation of sensitivity with a small temperature change in bars was noted. One bar spontaneously crazed at 64° F. This bar when bent gave an obviously inconsistent strain reading of 1200 micro inches/inch.

Test No. 118
 Date 6 Dec 1947
 Time 1100
 Wet Bulb 70° F
 Dry Bulb 70.5° F
 Atmospheric Pressure 30.04
 Atmospheric Correction 0.10
 Time of Loading Specimen 180 sec

Specimen Temp. at time of test failure: 69° F

| Strain Gage Name | Internal Pressure | Axial Load | Strain Gage (micro inches) |
|------------------|-------------------|------------|----------------------------|
| 1 | 0 | 0 | 1182 |
| 2 | 0 | 0 | 1182 |
| 3 | 0 | 0 | 1182 |
| 4 | 0 | 0 | 1182 |

Calibration Bar No. 1
 Strain, micro inches
 Time of Loading Bar, sec.
 Bar Temperature, degrees F

Remarks:
 It was necessary to cool bars and specimen to obtain sensitivity of strain gages. A marked variation of sensitivity with a small temperature change in bars was noted. One bar was consequently cooled at 64° F. This bar then gave an obviously inconsistent strain reading of 1200 micro inches/inch.

| | | |
|--------------------------|--------------------|-------------|
| <u>Test #19</u> | <u>Application</u> | <u>Test</u> |
| Date | 8 Dec 1947 | 9 Dec 1947 |
| Time | 1300 | 900 |
| Wet Bulb | 54° F | 54° F |
| Dry Bulb | 74° F | 73.5° F |
| #Stresscoat Used | #1206 | #1206 |
| #Stresscoat Called For | #1204 | |
| Time of Loading Specimen | | 40 sec. |

Specimen Temp. at time of coat failure: 73.5° F

| <u>Internal Pressure</u> <u>psi gage</u> | <u>Axial Load</u> <u>Lbs.</u> | <u>Strain Gage (micro inches)</u> | | | |
|---|----------------------------------|-----------------------------------|-----|-----|-----|
| | | 1 | 2 | 3 | 4 |
| 0 | 0 | 390 | 310 | 920 | 280 |
| | | #8 ref | #4 | #5 | #7 |
| 1200 | 0 | 530 | 785 | - | 700 |
| | | #8 | #4 | - | #7 |

| | | | | | | |
|----------------------------|------|-------|------|-------|-------|------|
| Calibration Bar No. | 1 | 2 | 3 | 4 | 5 | 6 |
| Strain, micro Inches | 550 | 450 | 440 | 490 | 490 | 440 |
| Time of Loading Bar, Secs. | 1 | 1 | 1 | 40 | 40 | 1 |
| Bar Temperature, degrees F | 74.5 | 73.75 | 73.5 | 73.75 | 73.75 | 73.5 |

| <u>Test #20</u> | <u>Application</u> | <u>Test</u> |
|--------------------------|--------------------|-------------|
| Date | 9 Dec 1947 | 10 Dec 1947 |
| Time | 1300 | 1300 |
| Wet Bulb | 54° F | 53° F |
| Dry Bulb | 74° F | 71.5° F |
| #Stresscoat Used | #1205 | #1205 |
| #Stresscoat Called For | #1203 | |
| Time of Loading Specimen | | 50 sec. |

Specimen temp. at time of coat failure: 71.5° F

| <u>Internal Pressure</u> <u>psi gage</u> | <u>Axial Load</u> <u>Lbs.</u> | <u>Strain Gage (micro inches)</u> | | | |
|---|----------------------------------|-----------------------------------|------|-----|------|
| | | 1 | 2 | 3 | 4 |
| 0 | 0 | 250 | 1190 | 620 | 1100 |
| | | #8 ref | #2 | #5 | #6 |
| 2050* | 0 | 475 | 1060 | 840 | 1940 |
| | | #8 | #4 | #5 | #6 |

| <u>Calibration</u> | | | | | | | | | | |
|---|------|------|--------|------|--------|------|------|------|------|------|
| <u>Bar No.</u> | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| <u>Strain,</u> <u>Micro Inches</u> | 700 | 700 | 860 | 900 | 670 | 780 | 730 | 810 | 790 | 905 |
| <u>Time of Load-</u> <u>ing Bar, Secs.</u> | 1 | 1 | 1 | 50 | 1 | 50 | 1 | 50 | 1 | 50 |
| <u>Bar Temperature</u> <u>degrees F</u> | 71.5 | 71.5 | 71.5** | 71.5 | 71.5** | 71.5 | 71.5 | 71.5 | 71.5 | 71.5 |

Remarks:

* This run was made after the specimen had been loaded in tension to the design strength of the specimen, but no circumferential cracks in stresscoat were noted. The stresscoat was allowed to recover for a time in excess of two times the time to load the specimen; before the internal pressure was applied.

** Bar number 3 was a thicker coat than the best specimen and Bar number 5 was an exceedingly thin coat.

| <u>Test #21</u> | <u>Application</u> | <u>Test</u> |
|--------------------------|--------------------|-------------|
| Date | 10 Dec 1947 | 11 Dec 1947 |
| Time | 1600 | 1300 |
| Wet Bulb | 53° F | 52° F |
| Dry Bulb | 71.5° F | 70.75° F |
| #Stresscoat Used | #1205 | #1205 |
| #Stresscoat Called For | #1202 | |
| Time of Loading Specimen | | 60 sec |

Temp. of specimen at time of coat failure: 70.75° F

| <u>Internal Pressure</u> <u>psi gage</u> | <u>Axial Load</u> <u>Lbs.</u> | <u>Strain Gage (micro inches)</u> | | | |
|---|----------------------------------|-----------------------------------|------|-----|-----|
| | | 1 | 2 | 3 | 4 |
| 0 | 0 | 240 | 180 | 590 | 80 |
| | | #8 ref | #4 | #5 | #7 |
| 2175* | 0 | 440 | 1090 | 830 | 980 |
| | | #8 | #4 | #5 | #7 |

| Calibration Bar No. | 1 | 2 | 3-A | 3-B | 4-A | 4-B | 5 |
|----------------------------|-------|-------|------|------|------|------|------|
| Strain, Micro Inches | 900 | 900 | 960 | 810 | 1010 | 800 | 800 |
| Time of Loading Bar, Secs. | 1 | 1 | 60 | 1 | 60 | 1 | 1 |
| Bar Temperature, degrees F | 70.75 | 70.75 | 71.5 | 71.5 | 71.5 | 71.5 | 71.5 |

Remarks:

- * This run was made after the specimen had been loaded in tension to the design strength of specimen but no cracks were noted in the Stresscoat. The Stresscoat was allowed to recover for a time in excess of two times the time allowed to load the specimen, before the internal pressure was applied.

5 29 78 6 12 20

1957

RECEIVED

THE authors gratefully acknowledge

100% of the total

004 0 0000

342 0 0

Internal Internal

1997-1998 2015-2016 2017

S061 701 001189 14C00000112

5061 kca 1000000000

08-17 d f u r p y c

6711

1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035 2036 2037 2038 2039 2040 2041 2042 2043 2044 2045 2046 2047 2048 2049 2050 2051 2052 2053 2054 2055 2056 2057 2058 2059 2060 2061 2062 2063 2064 2065 2066 2067 2068 2069 2070 2071 2072 2073 2074 2075 2076 2077 2078 2079 2080 2081 2082 2083 2084 2085 2086 2087 2088 2089 2090 2091 2092 2093 2094 2095 2096 2097 2098 2099 2100 2101 2102 2103 2104 2105 2106 2107 2108 2109 2110 2111 2112 2113 2114 2115 2116 2117 2118 2119 2120 2121 2122 2123 2124 2125 2126 2127 2128 2129 2130 2131 2132 2133 2134 2135 2136 2137 2138 2139 2140 2141 2142 2143 2144 2145 2146 2147 2148 2149 2150 2151 2152 2153 2154 2155 2156 2157 2158 2159 2160 2161 2162 2163 2164 2165 2166 2167 2168 2169 2170 2171 2172 2173 2174 2175 2176 2177 2178 2179 2180 2181 2182 2183 2184 2185 2186 2187 2188 2189 2190 2191 2192 2193 2194 2195 2196 2197 2198 2199 2200 2201 2202 2203 2204 2205 2206 2207 2208 2209 2210 2211 2212 2213 2214 2215 2216 2217 2218 2219 2220 2221 2222 2223 2224 2225 2226 2227 2228 2229 2230 2231 2232 2233 2234 2235 2236 2237 2238 2239 2240 2241 2242 2243 2244 2245 2246 2247 2248 2249 2250 2251 2252 2253 2254 2255 2256 2257 2258 2259 2260 2261 2262 2263 2264 2265 2266 2267 2268 2269 2270 2271 2272 2273 2274 2275 2276 2277 2278 2279 2280 2281 2282 2283 2284 2285 2286 2287 2288 2289 2290 2291 2292 2293 2294 2295 2296 2297 2298 2299 2300 2301 2302 2303 2304 2305 2306 2307 2308 2309 2310 2311 2312 2313 2314 2315 2316 2317 2318 2319 2320 2321 2322 2323 2324 2325 2326 2327 2328 2329 2330 2331 2332 2333 2334 2335 2336 2337 2338 2339 2340 2341 2342 2343 2344 2345 2346 2347 2348 2349 2350 2351 2352 2353 2354 2355 2356 2357 2358 2359 2360 2361 2362 2363 2364 2365 2366 2367 2368 2369 2370 2371 2372 2373 2374 2375 2376 2377 2378 2379 2380 2381 2382 2383 2384 2385 2386 2387 2388 2389 2390 2391 2392 2393 2394 2395 2396 2397 2398 2399 2400 2401 2402 2403 2404 2405 2406 2407 2408 2409 2410 2411 2412 2413 2414 2415 2416 2417 2418 2419 2420 2421 2422 2423 2424 2425 2426 2427 2428 2429 2430 2431 2432 2433 2434 2435 2436 2437 2438 2439 2440 2441 2442 2443 2444 2445 2446 2447 2448 2449 2450 2451 2452 2453 2454 2455 2456 2457 2458 2459 2460 2461 2462 2463 2464 2465 2466 2467 2468 2469 2470 2471 2472 2473 2474 2475 2476 2477 2478 2479 2480 2481 2482 2483 2484 2485 2486 2487 2488 2489 2490 2491 2492 2493 2494 2495 2496 2497 2498 2499 2500 2501 2502 2503 2504 2505 2506 2507 2508 2509 2510 2511 2512 2513 2514 2515 2516 2517 2518 2519 2520 2521 2522 2523 2524 2525 2526 2527 2528 2529 2530 2531 2532 2533 2534 2535 2536 2537 2538 2539 2540 2541 2542 2543 2544 2545 2546 2547 2548 2549 2550 2551 2552 2553 2554 2555 2556 2557 2558 2559 2560 2561 2562 2563 2564 2565 2566 2567 2568 2569 2570 2571 2572 2573 2574 2575 2576 2577 2578 2579 2580 2581 2582 2583 2584 2585 2586 2587 2588 2589 2590 2591 2592 2593 2594 2595 2596 2597 2598 2599 2600 2601 2602 2603 2604 2605 2606 2607 2608 2609 2610 2611 2612 2613 2614 2615 2616 2617 2618 2619 2620 2621 2622 2623 2624 2625 2626 2627 2628 2629 2630 2631 2632 2633 2634 2635 2636 2637 2638 2639 2640 2641 2642 2643 2644 2645 2646 2647 2648 2649 2650 2651 2652 2653 2654 2655 2656 2657 2658 2659 2660 2661 2662 2663 2664 2665 2666 2667 2668 2669 2670 2671 2672 2673 2674 2675 2676 2677 2678 2679 2680 2681 2682 2683 2684 2685 2686 2687 2688 2689 2690 2691 2692 2693 2694 2695 2696 2697 2698 2699 2700 2701 2702 2703 2704 2705 2706 2707 2708 2709 2710 2711 2712 2713 2714 2715 2716 2717 2718 2719 2720 2721 2722 2723 2724 2725 2726 2727 2728 2729 2730 2731 2732 2733 2734 2735 2736 2737 2738 2739 2740 2741 2742 2743 2744 2745 2746 2747 2748 2749 2750 2751 2752 2753 2754 2755 2756 2757 2758 2759 2760 2761 2762 2763 2764 2765 2766 2767 2768 2769 2770 2771 2772 2773 2774 2775 2776 2777 2778 2779 2780 2781 2782 2783 2784 2785 2786 2787 2788 2789 2790 2791 2792 2793 2794 2795 2796 2797 2798 2799 2800 2801 2802 2803 2804 2805 2806 2807 2808 2809

Page 001 of 001

not in line. 1st 1st

FAI 536 12

Test #22ApplicationTest

Date

11 Dec 1947

12 Dec 1947

Time

1600

1300

Wet Bulb

52° F

53° F

Dry Bulb

70.5° F

71° F

#Stresscoat Used

#1206

#1206

#Stresscoat Called For

#1202

Time of Loading Specimen

(A) 45 sec (B) 75 sec

Temp of Specimen at time of coat failure: 71.5° F

Internal
Pressure
psi gageAxial
Load
Lbs.Strain Gage (micro inches)

1

2

3

4

0

0

260

230

640

130

#8 ref

#4

#5

#7

(A)* 1900

0

480

980

830

870

#8

#4

#5

#7

(B) 1470

35000

935

660

1270

570

#8

#4

#5

#7

Calibration Bar No.

3A

3B

Strain, Micro Inches

730

730

Time of Loading Bar, Secs.

1

75

Bar Temperature, degrees F

71.5

71.5

Remarks:

Longitudinal cracks (very apparent) appeared with $P_1 = 1900$ psig. and $P_2 = 0$ in test A. Time of loading 45 sec. Circumferential cracks appeared with loading $P_1 = 1470$ psig. and $P_2 = 35000$ lbs. as indicated. Time of loading 75 secs.

Both the bars and the specimen were badly crazed, however, the cracks from loading were readily apparent on the specimen, but were almost impossible to see on the bars.

* This run was made after the specimen had been loaded in tension with no cracks appearing in stresscoat. It was allowed to recover.

100-1000

1992

2017

1975

0100 770

5000 1400007524

NOT RECORDED

remains subject to suit

2.15 minutes for a unit is required to cut

INVESTIGATION
PROGRESS
DATE

Latent
broad
...
...

~~(Sensational, sensational) and sensational~~

| 4 | 3 | 2 | 1 | 0 | |
|-----|------|-----|--------|-------|----------|
| 001 | 040 | 005 | 000 | 0 | 0 |
| 01 | 01 | 0 | 107 84 | | |
| 078 | 008 | 000 | 084 | 0 | 0001 (A) |
| 01 | 01 | 0 | 0 | | |
| 072 | 0701 | 000 | 000 | 00000 | 0701 (B) |
| 01 | 01 | 0 | 0 | | |

On the morning of

SECRET

...and

7-17 6-17 1980

[illegible]

but were almost impossible to see in the air. The crabs from localities were readily a source of the specimens, and the same in the specimens, and of a species, however, and a = 35000 feet, as indicated, the following 75 specimens. Differential crabs associated with locality 4, = 1470 feet. 7, = 1900 feet, and 10 = 0 in fact a time of locality 25 feet. Localities crabs (very abundant) associated with

to recover.
tension with no trace of strain in movement.
This run was made after the accident and
is located in the museum.

| <u>Test #23</u> | <u>Application</u> | <u>Test</u> |
|--------------------------|--------------------|-----------------------|
| Date | 12 Dec 1947 | 13 Dec 1947 |
| Time | 1500 | 1000 |
| Wet Bulb | 53° F | 54° F |
| Dry Bulb | 71° F | 70° F |
| #Stresscoat Used | #1207 | #1207 |
| #Stresscoat Called For | #1202 | |
| Time of Loading Specimen | | (A) 70 sec (B) 25 sec |

Temp of Specimen at time of coat failure: 70.5° F (A) & (B)

| Internal Pressure psi | Axial Load Lbs. | <u>Strain Gage (micro inches)</u> | | | |
|--------------------------|--------------------|-----------------------------------|---------|---------|---------|
| | | 1 | 2 | 3 | 4 |
| 0 | 0 | 315/#8 ref | 1260/#3 | 680/#5 | 1150/#6 |
| (A) 0 | 36,580 | 970/#8 | 1050/#3 | 1300/#5 | 970/#6 |
| 0 | 0 | 320/#8 | 270/#4 | 680/#5 | 140/#7 |
| (B) 1475 | 0 | 465/#8 | 860/#4 | 830/#5 | 745/#7 |

| <u>Calibration</u> | 1A | 1B | 2A | 3A | 4A | 4B | 5 | 6 |
|-----------------------------------|------|------|------|------|------|------|------|------|
| <u>Bar No.</u> | | | | | | | | |
| <u>Strain, Micro inches</u> | 870 | 580 | 450 | 450 | 700 | 560 | 520 | 500 |
| <u>Time of Loading Bar, Secs.</u> | 1 | 1 | 70 | 1 | 70 | 1 | 25 | 25 |
| <u>Bar Temperature, degrees F</u> | 74.5 | 70.5 | 70.5 | 70.5 | 70.5 | 70.5 | 70.5 | 70.5 |

Remarks:

Specimen and bars were heated to approximately 80°F during the drying period and then allowed to assume room temperature prior to the test.

Test (B) was made after the crack pattern of part (A) had been obtained. Sufficient time for creep recovery of the coat was allowed between tests.

Test 123 Date 12 Dec 1947 Time 1000 Wet bulb 70° F Dry bulb 70° F Atmospheric load 11507 Atmospheric cooling for 11507

Time of loading specimen 11507 (A) TO see (B) TO see

Time of specimen at time of test 11507 (A) TO see (B) TO see

| Initial pressure | Initial load | Initial temp | Initial strain | Initial time | Initial temp | Initial strain | Initial time |
|------------------|--------------|--------------|----------------|--------------|--------------|----------------|--------------|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| (A) 0 | 35,500 | 270/-8 | 1000/-3 | 1000/-3 | 1000/-3 | 1000/-3 | 1000/-3 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| (B) 1475 | 0 | 452/-8 | 1000/-3 | 1000/-3 | 1000/-3 | 1000/-3 | 1000/-3 |
| Calibration | 1A | 1B | 1C | 1D | 1E | 1F | 1G |
| Strain | 270 | 450 | 450 | 450 | 450 | 450 | 450 |
| Micro inches | 270 | 450 | 450 | 450 | 450 | 450 | 450 |
| Time of loading | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Bar. Temp. | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Bar. Temperature | 14.5 | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 |

Remarks:

Specimen and bars were heated to approximately 500° during the drying period and then allowed to assume room temperature prior to the test.

Test (B) was made after the above pattern of test (A) had been obtained. Sufficient time for stress recovery of the cast was allowed between tests.

| <u>Test #24</u> | <u>Application</u> | <u>Test</u> |
|--|--------------------|-----------------------|
| Date | 15 Dec 1947 | 16 Dec 1947 |
| Time | 1200 | 1000 |
| Wet Bulb | 54°F | 58°F |
| Dry Bulb | 73°F | 76°F |
| #Stresscoat Used | #1208 | #1208 |
| #Stresscoat Called For | #1203 | |
| Time of Loading Specimen | | (A) 65 sec (B) 25 sec |
| Temp. of specimen at time coat failed: | 76°F | |

| <u>Internal Pressure</u> <u>psi gage</u> | <u>Axial Load</u> <u>Lbs.</u> | <u>Strain Gage (micro inches)</u> | | | |
|---|----------------------------------|-----------------------------------|---------|---------|---------|
| | | 1 | 2 | 3 | 4 |
| 0 | 0 | 375/#8 | 1330/#3 | 725/#5 | 1200/#6 |
| (A) 0 | 36,000 | 1045/#8 | 1155/#3 | 1360/#5 | 1050/#6 |
| 0 | 0 | 380/#8 | 360/#4 | 740/#5 | 230/#7 |
| (B) 1625 | 0 | 540/#8 | 970/#4 | 885/#5 | 845/#7 |
| 0 | 0 | 425/#8 | 350/#4 | 720/#5 | 195/#7 |

| <u>Calibration</u> <u>Bar No.</u> | 1 | 2A | 2B | 3 | 4 | 5 | 6A* | 6B* |
|---|-----|-----|-----|-----|-----|-----|-----|-----|
| <u>Strain,</u> <u>Micro Inches</u> | 490 | 590 | 530 | 600 | 540 | 590 | 690 | 520 |
| <u>Time of Loading</u> <u>Bar, Secs.</u> | 1 | 65 | 1 | 65 | 1 | 25 | 25 | 1 |
| <u>Bar Temperature,</u> <u>degrees F</u> | 76 | 76 | 76 | 76 | 76 | 76 | 76 | 76 |

Remarks:

Bar #6 was crazed.

Test (B) was made after the crack pattern of Part (A) had been obtained. Sufficient time for creep recovery of the coat was allowed between tests.

Test 124

Date

Time

Test Bulb

Dry Bulb

Atmosphere Used

Atmosphere Called For

Calibration

12 Dec 1947

1000

2400

7500

41208

41203

Test

12 Dec 1947

1000

2400

7500

41208

Time of Loading Specimen

(1) 25 sec (2) 25 sec

Temp. of specimen at time test called: 7500

| Internal Pressure psi | Axial Load lbs | Strain gage (micro inches) |
|-----------------------|----------------|----------------------------|
| 0 | 0 | 1500/16 |
| (A) 0 | 36,000 1042/18 | 1752/12 1350/12 1250/12 |
| 0 | 3600/16 | 330/14 240/12 220/12 |
| (B) 1625 | 0 | 240/12 220/12 220/12 |
| 0 | 425/16 | 330/14 120/12 120/12 |

Calibration

Bar No.

Strain

Micro inches

Time of Loading

Bar Temp.

Bar Temperature

Specimen Temp

| | | | | | | | |
|-----|-----|-----|-----|-----|-----|-----|-----|
| 1 | 24 | 28 | 2 | 4 | 2 | 24 | 24 |
| 400 | 300 | 250 | 600 | 240 | 250 | 250 | 250 |
| 1 | 25 | 1 | 25 | 1 | 25 | 25 | 25 |
| 75 | 75 | 75 | 75 | 75 | 75 | 75 | 75 |

Remarks:

Bar 26 was ground.

Test (B) was made after the crack pattern of test (A) had been obtained. Sufficient time for stress recovery of the coat was allowed between tests.

| <u>Test #25</u> | <u>Application</u> | <u>Test</u> |
|--|-----------------------|-------------|
| Date | 16 Dec 1947 | 17 Dec 1947 |
| Time | 1300 | 1400 |
| Wet Bulb | 58°F | 56½°F |
| Dry Bulb | 76°F | 75°F |
| #Stresscoat Used | #1208 | #1208 |
| Time of Loading Specimen | (A) 35 sec (B) 28 sec | |
| Temp. of Specimen at time of coat failure: | 76.5°F | |

| <u>Internal Pressure</u> <u>psi gage</u> | <u>Axial Load</u> <u>Lbs.</u> | <u>Strain Gage (micro inches)</u> | | | |
|---|----------------------------------|-----------------------------------|---------|---------|---------|
| | | 1 | 2 | 3 | 4 |
| 0 | 0 | 385/#8 | 1270/#3 | 705/#5 | 1175/#6 |
| (A) 0 | 34,000 | 940/#8 | 1095/#3 | 1285/#5 | 1010/#6 |
| 0 | 0 | 320/#8 | 290/#4 | 695/#5 | 180/#7 |
| (B) 1330 | 0 | 470/#8 | 810/#4 | 850/#5 | 695/#7 |

| <u>Calibration</u> | 1 | 2A | 3 | 4 | 5A | 5B | 6A | 6B |
|---|------|------|-----|-----|-----|-----|-----|-----|
| <u>Bar No.</u> | | | | | | | | |
| <u>Strain,</u> <u>micro inches</u> | 530 | 580 | 500 | 540 | 530 | 620 | 540 | 540 |
| <u>Time of Loading</u> <u>Bar, Secs.</u> | 1 | 35 | 1 | 35 | 1 | 28 | 1 | 28 |
| <u>Bar Temperature,</u> <u>degrees F</u> | 76.5 | 76.5 | 75 | 75 | 75 | 75 | 75 | 75 |

Remarks:

All of the bars were slightly crazed both from drying and from low temperature. It so happened that the craze markings were indiscriminate in direction so that strain cracks could be readily seen. There was no craze on the specimen.

Test (B) was made after the crack pattern of Part (A) had been obtained. Sufficient time for creep recovery of the coat was allowed between tests.

| Test 457 | Application | Test |
|--|-------------|-------------|
| Date | 16 Dec 1947 | 17 Dec 1947 |
| Time | 1300 | 1400 |
| Wet Bulb | 78°F | 78°F |
| Dry Bulb | 76°F | 75°F |
| Hygrometer Read | 1208 | 1208 |
| Time of Loading Specimen (A) 25 sec (B) 28 sec | | |

| Temp. of Specimen at Time of coat failure: 76.5°F | | Time of Loading Specimen | | | | |
|---|--------|--------------------------|---------|----------------------------|---------|-----|
| Internal Pressure | | Axial Load | | Strain Rate (Micro Inches) | | |
| psi | lb. | 1 | 2 | 3 | 4 | 5 |
| 0 | 0 | 382/48 | 1230/42 | 1021/42 | 1112/46 | |
| 0 | 34,000 | 340/48 | 1022/42 | 1282/42 | 1010/46 | |
| 0 | 0 | 350/48 | 500/44 | 622/42 | 180/47 | |
| 0 | 1230 | 470/48 | 870/44 | 820/42 | 622/47 | |
| Calibration | | | | | | |
| Bar No. | | | | | | |
| Strain | | | | | | |
| Micro Inches | | | | | | |
| Time of Loading | | | | | | |
| Bar, 0.002 | | | | | | |
| Bar Temperature | | | | | | |
| Degrees F | | | | | | |
| 76.5 | 76.5 | 75 | 75 | 75 | 75 | 75 |
| 1 | 35 | 1 | 35 | 1 | 35 | 1 |
| 230 | 280 | 200 | 240 | 230 | 240 | 240 |
| 1 | 24 | 3 | 4 | 24 | 28 | 64 |

Remarks:

All of the bars were slightly cracked after loading and from low temperature. It was observed that the cracks were indeterminate in direction and that certain cracks could be readily seen. There was no crack on the specimen.

Test (B) was made after the crack pattern of test (A) had been obtained. Sufficient time for stress recovery of the coat was allowed between tests.

| <u>Test #26</u> | <u>Application</u> | <u>Test</u> |
|---|-----------------------|-------------|
| Date | 17 Dec 1947 | 18 Dec 1947 |
| Time | 1600 | 1300 |
| Wet Bulb | 56.5°F | 58°F |
| Dry Bulb | 75°F | 74°F |
| #Stresscoat Used | #1208 | #1208 |
| Time of Loading Specimen | (A) 50 sec (B) 35 sec | |
| Temp. of Specimen at time of coat failure: 75.5°F | | |

| <u>Internal Pressure</u> <u>psi gage</u> | <u>Axial Load</u> <u>Lbs.</u> | <u>Strain Gage (micro inches)</u> | | | |
|---|----------------------------------|-----------------------------------|---------|---------|---------|
| | | 1 | 2 | 3 | 4 |
| 0 | 0 | 370/#8 | 1315/#3 | 730/#5 | 1210/#6 |
| (A) 0 | 37,000 | 1050/#8 | 1130/#3 | 1400/#5 | 1050/#6 |
| 0 | 0 | 400/#8 | 370/#4 | 770/#5 | 250/#7 |
| (B) 1600 | 0 | 620/#8 | 1010/#4 | 940/#5 | 890/#7 |

| | | | | | | |
|----------------------------|------|------|------|------|------|------|
| Calibration Bar No. | 1 | 2 | 3 | 4 | 5 | 6 |
| Strain, Micro Inches | 580 | 600 | 600 | 585 | 600 | 640 |
| Time of Loading Bar, Secs. | 1 | 50 | 50 | 35 | 35 | 35 |
| Bar Temperature, degrees F | 76.5 | 75.5 | 75.5 | 75.5 | 75.5 | 75.5 |

Remarks:

Bars badly crazed - Specimen had very little craze.

Test (B) was made after the crack pattern of part (A) had been obtained. Sufficient time for creep recovery of the coat was allowed between tests.

| Test No. | Date | Time | Net Wt | Dry Wt | Watercontent (Wt %) |
|----------|-------------|------|--------|--------|---------------------|
| Test 126 | 17 Dec 1947 | 1800 | 26.25g | 22.1g | 15.8 |
| Test 127 | 18 Dec 1947 | 1300 | 26.1g | 24.1g | 13.08 |

Time of loading specimen 15.5 sec
 Temp. of specimen at time of test failure: 75.5°

| Internal Pressure psi | External Load lbs. | 1 | 2 | 3 | 4 | Strain, where failure | Time of loading test, sec. | Bar temperature, degrees - 75.5 75.5 75.5 75.5 |
|--|--------------------|---------|---------|---------|---------|-----------------------|----------------------------|--|
| 0 | 0 | 270/48 | 115/45 | 130/45 | 120/45 | | | |
| (A) 0 | 27,000 | 1050/48 | 1150/45 | 1400/45 | 1050/45 | | | |
| 0 | 0 | 450/48 | 370/44 | 170/45 | 250/47 | | | |
| (B) 1800 | 0 | 650/48 | 1010/44 | 940/45 | 890/47 | | | |
| Calibration Bar No. 1 | | | | | | | | |
| Strain, where failure | | | | | | | | |
| Time of loading test, sec. | | | | | | | | |
| Bar temperature, degrees - 75.5 75.5 75.5 75.5 | | | | | | | | |

Remarks:
 Bars badly cracked - fracture and very little stress.
 Test (B) was made after bar had cooled to room temp. (A) had been obtained. Calibration bar had been recovered of the cost was allowed before tests.

| | | |
|------------------|--------------------|-------------|
| <u>Test #27</u> | <u>Application</u> | <u>Test</u> |
| Date | 18 Dec 1947 | 19 Dec 1947 |
| Time | 1300 | 1500 |
| Wet Bulb | 58°F | 57°F |
| Dry Bulb | 74°F | 74°F |
| #Stresscoat Used | #1207 | #1207 |

Time of Loading Specimen (A) 55 sec (B) 35 sec

Temp. of Specimen at time of coat failure: 74°F

| Internal Pressure psi gage | Axial Load Lbs. | <u>Strain Gage (micro inches)</u> | | | |
|-------------------------------|--------------------|-----------------------------------|---------|---------|---------|
| | | 1 | 2 | 3 | 4 |
| 0 | 0 | 365/#8 | 1320/#3 | 735/#5 | 1200/#6 |
| (A) 0 | 35,200 | 1045/#8 | 1150/#3 | 1340/#5 | 1030/#6 |
| 0 | 0 | 380/#8 | 345/#4 | 745/#5 | 225/#7 |
| (A) 1600 | 0 | 570/#8 | 1000/#4 | 925/#5 | 860/#7 |

| | | | | | | | | |
|-----------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|
| <u>Calibration</u> | | | | | | | | |
| <u>Bar No.</u> | 1 | 2 | 3 | 4 | 5A | 6A | 5B | 6B |
| <u>Strain, Micro Inches</u> | 570 | 580 | 580 | 570 | 550 | 540 | 550 | 490 |
| <u>Time of Loading Bar, Secs.</u> | 1 | 55 | 55 | 55 | 35 | 35 | 1 | 1 |
| <u>Bar Temperature, degrees F</u> | 74 | 74 | 74 | 74 | 74 | 74 | 74 | 74 |

| Test Test | Application | Test |
|------------------|-------------|-------------|
| Date | 18 Dec 1967 | 18 Dec 1967 |
| Time | 1200 | 1200 |
| Wet Bulb | 80°F | 80°F |
| Dry Bulb | 70°F | 70°F |
| Atmospheric Load | 1507 | 1507 |

Time of Loading Specimen (A) 25 sec (B) 25 sec
Temp. of Specimen at Time of Load Failure: 140°F

| Internal Pressure | Internal Load | Strain Rate (micro inches) |
|-------------------|---------------|----------------------------|
| psi | lbs | |
| 0 | 0 | 1300/45 |
| 0 (A) | 25,200 | 1300/45 |
| 0 | 0 | 1300/45 |
| 0 (A) | 0 | 1300/45 |

| Bar No. | Strain, Micro Inches | Time of Loading, Secs. | Bar Temperature, °F |
|---------|----------------------|------------------------|---------------------|
| 1 | 250 | 25 | 74 |
| 2 | 250 | 25 | 74 |
| 3 | 250 | 25 | 74 |
| 4 | 250 | 25 | 74 |
| 5 | 250 | 25 | 74 |
| 6 | 250 | 25 | 74 |
| 7 | 250 | 25 | 74 |
| 8 | 250 | 25 | 74 |

| <u>Test #28</u> | <u>Application</u> | <u>Test</u> |
|------------------|--------------------|-------------|
| Date | 19 Dec 1947 | 20 Dec 1947 |
| Time | 1600 | 1000 |
| Wet Bulb | 57°F | 56°F |
| Dry Bulb | 74°F | 72.5°F |
| #Stresscoat Used | #1205 | #1205 |

| <u>Calibration</u> <u>Bar No.</u> | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|------|------|------|------|------|------|------|------|------|------|
| <u>Strain,</u> <u>Micro Inches</u> | 680 | 620 | 630 | 780 | 820 | 850 | 700 | 630 | 620 | 600 |
| <u>Time of Loading Bar</u> <u>Secs.</u> | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 1 | 1 | 1 |
| <u>Bar Temperature, de-</u> <u>grees F</u> | 72.5 | 72.5 | 72.5 | 72.5 | 72.5 | 72.5 | 72.5 | 72.5 | 72.5 | 72.5 |

Remarks:

Bars #4, #5, #6 were purposely crazed by exposure to cool air and then were allowed to return to room temperature.

The average Stresscoat thickness on each of the ten bars tested was between .0065" and .0075".

| Test | Application | Test |
|-------------|-------------|-------------|
| 30 Dec 1947 | 19 Dec 1947 | 30 Dec 1947 |
| 1000 | 1000 | 1000 |
| 500 | 500 | 500 |
| 15.5 | 14.0 | 15.5 |
| 1100 | 1100 | 1100 |
| | | 1100 |

| Bar No. | Calibration | Bar No. | Calibration |
|---------|-------------|---------|-------------|
| 1 | 1 | 1 | 1 |
| 2 | 2 | 2 | 2 |
| 3 | 3 | 3 | 3 |
| 4 | 4 | 4 | 4 |
| 5 | 5 | 5 | 5 |
| 6 | 6 | 6 | 6 |
| 7 | 7 | 7 | 7 |
| 8 | 8 | 8 | 8 |
| 9 | 9 | 9 | 9 |
| 10 | 10 | 10 | 10 |

Bar No. 45, 46 were purposely covered by exposure to cool air and then were allowed to return to room temperature.

The average pressure thickness on each of the ten bars tested was between .005" and .0075".

APPENDIX D
BIBLIOGRAPHY

| <u>Title</u> | <u>Author</u> |
|--|--|
| 1. <u>Strength of Materials, Part II</u> | S. Timoshenko |
| 2. <u>Resistance of Materials</u> | F. B. Seely |
| 3. <u>Theory of Elasticity</u> | S. Timoshenko |
| 4. "Application of the Brittle Lacquer Method in the Stress Analysis of Machine Parts", <u>Proceedings of the Society for Experimental Stress Analysis, Vol. 1, No. 2, 1944, Page 116.</u> | M. Hetinye |
| 5. "Brittle Coatings for Quantitative Strain Measurements", <u>Journal of Applied Mechanics, Vol. 9, No. 4, Dec. 1942, Page A184</u> | A. V. DeForest Greer Ellis F. B. Stern |
| 6. "Experimental Determination of Iso-static Lines", <u>Journal of Applied Mechanics, Vol. 9, No. 4, Dec. 1942, Page A155.</u> | A. J. Durelli |
| 7. "Practical Strain Analysis By Use of Brittle Coatings", <u>Proceedings of Society for Experimental Stress Analysis, Vol. 1, No. 1, 1943, Page 46</u> | Greer Ellis |
| 8. M.I.T. Master's Thesis, "Strain Indicating Lacquers", 1937 | Greer Ellis |
| 9. "Brittle Lacquers as an Aid to Stress Analysis", <u>Journal of Aeronautical Sciences, Vol. 7, 1940, Page 205</u> | A. V. DeForest Greer Ellis |
| 10. "Stress Strain Analysis from Crack Formations in Brittle Lacquer Coating", <u>Product Engineering, Vol. 11, 1940 Page 263.</u> | |
| 11. M.I.T. Bachelor's Thesis, "Investigation of the Limits of Accuracy of Stresscoat", 1941 | C. E. Olsen, Jr. |

AMERICAN
PHYSICS

| Author | Title |
|--|--|
| | 1. <u>Strength of Materials</u> , Part II |
| | 2. <u>Resistance of Materials</u> |
| | 3. <u>Theory of Elasticity</u> |
| | 4. <u>"Application of the Elastic Theory Methods in the Stress Analysis of Machine Parts", Proceedings of the Society for Experimental Stress Analysis, Vol. I, No. 2, 1944, Page 116.</u> |
| A. R. A. | 5. <u>"Elastic Constants for Compressive Strain Measurements", Journal of Applied Mechanics, Vol. 9, No. 4, Dec. 1942, Page 419.</u> |
| | 6. <u>"Experimental Determination of the Static Stress", Journal of Applied Mechanics, Vol. 9, No. 4, Dec. 1942, Page 419.</u> |
| | 7. <u>"Torsional Strain Analysis of Machine Components", Proceedings of Society for Experimental Stress Analysis, Vol. I, No. 1, 1944, Page 45.</u> |
| | 8. <u>"Torsional Analysis of Machine Components", 1944</u> |
| A. | 9. <u>"Elastic Properties of Machine Components", Journal of Mechanical Engineering, Vol. 6, 1940, Page 303.</u> |
| | 10. <u>"Torsional Analysis of Machine Components", 1944</u> |
| | 11. <u>"Torsional Analysis of Machine Components", 1944</u> |

APPENDIX D
BIBLIOGRAPHY

- | <u>Title</u> | <u>Author</u> |
|---|---------------------------|
| 12. M.I.T. Bachelor's Thesis, "Yield Point Indicators", 1940 | B. Feldman |
| 13. "Stress Determination by Brittle Coatings", <u>Mechanical Engineering</u> , Vol. 69, No. 7, July 1947, Page 567. | Greer Ellis |
| 14. "Stress Determination", <u>Mechanical Engineering</u> , Vol. 69, No. 12, Dec. 1947, Page 1049. | A. J. Durelli |
| 15. "Practical Reduction Formulas for Use on Bonded Wire Strain Gauges in Two Dimensional Stress Fields," <u>Proceedings of Society for Experimental Stress Analysis</u> , Vol. 2, No. 1, 1944, Page 113. | R. Baumberger E. Hines |
| 16. Operating Instructions for Stresscoat, Magnaflux Corp. | |

APPENDIX D

BIBLIOGRAPHY

- | Author | Title |
|--------------------------|---|
| W.T.T. Bachelor's Thesis | "Point Indicators", 1940 |
| Green Ellis | "Stress Determination by Brittle Coatings", <u>Mechanical Engineering</u> , Vol. 69, No. 7, July 1947, Page 507. |
| Green Ellis | "Stress Determination", <u>Mechanical Engineering</u> , Vol. 69, No. 12, Dec. 1947, Page 1049. |
| Green Ellis | "Practical Reduction Formula for Use on Rotated Wire Strain Gages", <u>Proceedings of Society for Experimental Stress Analysis</u> , Vol. 3, No. 1, 1944, Page 117. |
| Green Ellis | "Operating Instructions for Stress Analysis Form." |

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Francis

6504

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